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Chamlin and Associates, Inc, Peru, Ill

Prepared for

Municipal Environmental Research Lab, Cincinnati, Ohio

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THE CONSTRUCTION, TECHNICAL EVALUATION, AND FRICTIONAL DETERMINATION OF AN ALUMINUM STORM SEWER SYSTEM

Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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16. ABSTRACT

The program consisted of analysis of the effect upon the quantity of sewerage flows in a portion of the existing combined system as a result of the construction of a demonstration aluminum storm sewer system, laboratory testing of flow characteristics of aluminum pipe, design and construction of a demonstration aluminum storm sewer system and appurtenances and the technical evaluation of the demonstration aluminum storm sewer system over a 10 year post-construction period.

Laboratory testing of flow characteristics of aluminum pipe was performed at the St. Anthony Falls Hydraulic Laboratory at the University of Minnesota in Minneapolis, Minnesota.

Evaluation of the demonstration aluminum storm sewer system is being accomplished by annual inspection tours consisting of collection of wastewater samples for determination of heavy metal content, pH, and minimum resistivity and aluminum sample coupons which are analyzed for corrosion and abrasion wear in the laboratory. Also measurements of deflection are taken at select locations to observe the structural performance of the completed aluminum demonstration sewer.

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DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problems.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and search for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The need exists to establish answers to special needs such as reduction of infiltration and improvement in sewer construction materials and methods to control pollution from urban runoff. This report presents a comprehensive evaluation of aluminum pipe as a storm sewer material.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

ABSTRACT

A Research and Development Program to technically evaluate the various aspects of an aluminum storm sewer system was undertaken by the City of LaSalle, Illinois, its Consulting Engineering firm, Chamlin & Associates, Inc., and the Aluminum Association. The program was sponsored by the Federal Water Pollution Control Administration (now the Environmental Protection Agency) designated as Project No. 11032 DTI. The program consisted of analysis of the effect upon the quantity of sewerage flows in a portion of the existing combined system as a result of the construction of a demonstration aluminum storm sewer system, laboratory testing of flow characteristics of aluminum pipe, design and construction of a demonstration aluminum storm sewer system and appurtenances and the technical evaluation of the demonstration aluminum storm sewer system over a 10 year post-construction period.

The typical effects of sewer separation resulting from the construction of the demonstration aluminum storm sewer system upon the quantity of the wastewater in a selected portion of the existing combined sewer system were observed by the use of a continuous recording flow measuring device installed at a strategic location in the existing combined sewer system.

Laboratory testing of flow characteristics of aluminum pipe was performed at the St. Anthony Falls Hydraulic Laboratory at the University of Minnesota in Minneapolis, Minnesota.

The demonstration aluminum storm sewer system was designed by Chamlin & Associates, Inc., of Peru, Illinois. The material contract was awarded to Kaiser Aluminum and Chemical Sales, Inc., P.O. Box 599, Bedford, Indiana 47421. The contract for installation of the aluminum pipe was awarded to Central Illinois Contracting Corporation, P.O. Box 140, Peru, Illinois.

Evaluation of the demonstration aluminum storm sewer system is being accomplished by annual inspection tours consisting of collection of wastewater samples for determination of heavy metal content, pH, and minimum resistivity and aluminum sample coupons which are analyzed for corrosion and abrasion wear in the laboratory. Also measurements of deflection are taken at select locations to observe the structural performance of the completed aluminum demonstration sewer.

This report was submitted in fulfillment of Project No. 11032 DTI by Chamlin & Associates, Inc., under the sponsorship of the Environmental Protection Agency. Construction work was completed as of June 30, 1973. Evaluation work will continue through 1983.

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Cooperation by all Officials of the City of LaSalle during the period of time encompassed by the project, and especially Mr. Quinto Pattelli, Superintendent of Public Works for the City of LaSalle, is acknowledged.

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Major contributions to the design, construction staking, resident inspection and subsequent evaluation, were made by various members of the staff of Chamlin & Associates, Inc..

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SECTION A

CONCLUSIONS

1. One of the original objectives of the program was to determine the effects of sewer separation upon the quality of the wastewater in the existing combined sewer system. This was to be accomplished by collecting wastewater quality samples prior to, during, and subsequent to construction of the Demonstration Aluminum Storm Sewer. After initiation of this project, it was determined that this objective could not be accomplished within the scope of the plan originally developed for this phase of the program. This was primarily due to the fact that the scope of testing required would not be justified from an economic standpoint, and could not be accomplished within the program budget.

2. When direct connections in the form of street inlets are eliminated by the construction of a separate storm sewer system, the total daily flows during rainfall periods decrease substantially. However, noticeable increases continue to occur during rainfall periods. This is undoubtedly the result of non-eliminated downspout connections, foundation drains, infiltration of groundwater, and other unknown sources of connection to the combined sewer system.

3. Complete information with regard to the friction factors to be utilized for the design of corrugated aluminum pipes flowing full may be obtained from a separate report published as part of this project referred to as Project Report No. 121 entitled"Further Studies of Friction Factors for Corrugated Aluminum Pipes Flowing Full"by Edward Silberman and Warren Q. Dahlin of the University of Minnesota, St. Anthony Falls Hydraulic Laboratory.

4. It was extremely difficult to maintain meaningful cost records during construction because the method of construction utilized for the installation of aluminum pipe is essentially identical to the method of construction utilized for the installation of any other kind of material. There was not available detailed cost records for any other project utilizing material other than aluminum pipe which could be used for comparison purposes. However, an evaluation of aluminum pipe compared to other materials was prepared and

is included in Section I of this report. It may be concluded that the most significant cost advantages resulting from the utilization of aluminum pipe are the first cost of the material itself and the obvious cost advantage of being able to install the aluminum pipe material in relatively long lengths utilizing only two men with ropes to lower the pipe into the trench rather than the necessity of having a separate piece of equipment to lift and lower heavier pipe into the trench. Observation of the construction procedures in comparison with projects utilizing other storm sewer material indicate that the degree of advantage to the use of aluminum pipe from the standpoint of material weight is somewhat proportional to the length of trench which can be excavated on a per day basis. Obviously in congested urban areas the amount of lineal footage of trench which can be excavated is not always controlled by the amount of pipe which can be placed, but rather by the limitation imposed by existing underground utilities and traffic conditions. Utilization of 20-foot long sections of aluminum pipe was generally an advantage from the standpoint of ease of installation and less joints. Utilization of lengths shorter than the standard 20-foot lengths was accomplished by simply using a power hand saw to cut the pipe to the desired length. The sawing operation required only a minimal time and did not delay construction progress. Slight alignment and grade changes could be accomplished by the utilization of heat shrinkable coupling bands which allowed as much as a 20 degree bend at the joints without sacrificing strength or watertightness. General handling of aluminum pipe from the time it arrives on the job site until the time it is installed in the ground is easier by virtue of its light weight. An apparent disadvantage to the use of aluminum pipe is the comparative weakness of the pipe unit itself under a non-load condition which is more easily damaged during construction procedures from general contact with the pipe by construction equipment, vandalism and caving trenches. Aluminum manholes and inlets required approximately the same amount of time and equipment to construct as comparable concrete structures with the only advantage to the aluminum being ease of handling due to its light weight.

5. After three years of service the demonstration aluminum storm sewer system utilizing aluminum alloys 3004 and 5052 appears to be in excellent condition. The extent of corrosion observed has an apparent insignificant effect upon the structural integrity of the standard corrugation, helical corrugation circular pipe and the structural plate arch. The extent of corrosion observed on the 3004 aluminum alloy sampled during the first three years is limited to the cladding material and no attack has been observed upon the

core material. Corrosion attack from the water side (interior of the pipe) is virtually non-existent. Corrosion observed upon the soil side of the pipe has subsided substantially since the first annual inspection tour.

SECTION B

RECOMMENDATIONS

1. It is recommended that work performed by the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota published as Project Report No. 121 entitled "Further Studies of Friction Factors for Corrugated Aluminum Pipes Flowing Full" by Edward Silberman and Warren Q. Dahlin be utilized for the selection of appropriate friction factors during the design stages of storm sewers utilizing aluminum pipe.

2. It is recommended that aluminum pipe be seriously considered for incorporation into Federal and State Specifications for projects involving the construction of storm sewer systems. Inclusion of aluminum material as an acceptable alternate in proposals for storm sewer construction work will result in the lowest obtainable project cost because of the competitive situation posed by the use of alternate materials.

3. It is recommended that evaluation work continue until 1983 at which time ten annual inspection tours will have been completed.

SECTION C

INTRODUCTION

The City of LaSalle, Illinois, had been experiencing difficulties with its combined sewer system for many years. The system had become increasingly inadequate to accommodate surface runoff during moderate and high intensity rainfall periods. This was due to inadequate foresight in the design of the combined system in conjunction with deterioration of the sewer system and increasing runoff as a result of increased development throughout the City and surrounding areas. The system became acutely inadequate in various areas of the City with the result being severe backup and flooding conditions during rainfall periods. In the late 1960's, the City was directed by the then State Sanitary Water Board to achieve practical separation of storm and sanitary sewers by the year 1978 in order to comply with the then current water pollution regulations. That requirement is no longer in effect since passage of Public Law 92-500 which is cited as the Federal Water Pollution Control Act Amendments of 1972. However, at the time of application for this grant, the City was legally obligated to provide practical separation of storm and sanitary sewers and the City Administration considered this a high priority project not only because of the legal obligation, but just as importantly because of the severe hardships being imposed upon the residents as a result of backup and flooding conditions. The City had in its possession a report on sewage and drainage prepared in 1967 which outlined a total separation project for the entire City. The present sewer system is comprised of a system which was originally a sanitary sewer system and has since developed into a sanitary sewer system subjected to hydraulic overloading in conjunction with a combined sewer system in the form of relief sewers. Sewer sizes range from 8" to 54" with the most common pipe size being 8". The larger diameter sewers are either interceptor type or relief sewers. The oldest sewers in the City were constructed in the late 1800's. The majority of the sewers are of vitrified clay or concrete construction. Sometime during the late 1800's or early 1900's, a relatively large interceptor sewer was constructed along First Street from Crosat Street westerly to Wright Street. This sewer was constructed by mining out a tunnel in a clay seam in the rock strata and lining it with bricks. In 1936, this interceptor was rebuilt and extended westward to Creve Coeur Street and remains today as the major interceptor sewer collecting combined flows and directing them to the sewage treatment plant facility. Many of the sewers throughout the City are in poor repair and the carrying capacities have been substantially reduced as a result of settlement, tree root growth and structural failure. The geographic area served by the demonstration aluminum storm sewer is one which is presently subjected to rather severe backup and flooding conditions during light to moderate rainfall periods. The report indicated at the time that the most cost-effective method of achieving practical separation was to construct separate storm sewer systems throughout the City allowing the existing combined system to be maintained as a separate sanitary sewer system. Conventional materials utilized for recent storm sewer construction included essentially concrete and some vitrified clay. The City was approached by representatives of the Aluminum Association through its consulting engineer to consider the possibility of using aluminum pipe as a storm sewer material for construction of storm sewers to achieve separation. It was learned through EPA (then F.W.P.C.A.) literature that research and development grants were available and a follow up by a team consisting of the City Administration, its consulting engineers, and the Aluminum Association resulted in a grant in the amount of $454,000.00 to construct an Aluminum Storm Sewer System and technically evaluate aluminum as a storm sewer material. The scope of the project involved the construction of approximately 18,300 lineal feet of aluminum storm sewer ranging in diameter from 12 inch to 72 inch in conjunction with a technical evaluation of the construction procedures and the effects of wastewater and various soils upon the aluminum material and pertinent structures.

The project was essentially divided into three major phases. The first phase involved the evaluation of the quantity and quality of flows in the existing combined sewer system. The second phase involved the design and construction of the aluminum storm sewer system, and appurtenances in conjunction with continued evaluation of the quantity and quality of sewerage flow in the existing combined sewer system. The third and most significant phase involved the technical evaluation of the aluminum storm sewer material subsequent to construction in conjunction with evaluation of the quality of sewerage flows within the system over a ten year period. The detailed program consisted of the following:

OBSERVATION OF EFFECTS OF SEWER SEPARATION UPON THE QUANTITY OF THE WASTEWATER IN THE EXISTING COMBINED SEWER SYSTEM

The objectives of this phase of the program were to determine the effects upon the quantity of sewage flowing in the combined sewer system prior to, during, and after removal of surface water contributed by roof leaders and street inlets.

LABORATORY TESTING OF FLOW CHARACTERISTICS OF ALUMINUM PIPE

The objective of this phase of the program was to determine the flow characteristics such as the theoretical friction factors or "N" values for corrugated aluminum pipes flowing full. This work was performed at the St. Anthony Falls Hydraulic Laboratory at the University of Minneapolis, Minnesota, and the results were published as Project Report No. 121 entitled "Further Studies of Friction Factors for Corrugated Aluminum Pipes Flowing Full" by Edward Silberman and Warren Q. Dahlin.

DESIGN OF AN INTEGRATED ALUMINUM DEMONSTRATION STORM SEWER SYSTEM AND APPURTENANCES

This phase of the program consisted of the preparation of detailed plans and specifications for a demonstration aluminum storm sewer system consisting of approximately 18,000 lineal feet of aluminum storm sewers ranging in diameter from 12 inch to 72 inch. Design of special coupling devices, manhole and street inlets, and other appurtenances were incorporated into the plans.

CONSTRUCTION OF DEMONSTRATION STORM SEWER SYSTEM AND APPURTENANCES

This phase of the program involved the advertisement for bids, awarding of Contracts, and construction of the aluminum storm sewer system in accordance with the plans and specifications prepared. During construction of the demonstration sewer, an attempt was made to consider the cost factors resulting from use of aluminum pipe as well as to observe the installation factors of aluminum pipe versus other materials.

EVALUATION OF DEMONSTRATION STORM SEWER SYSTEM AND APPURTENANCES

The objectives of this phase of the program are to technically evaluate the installed demonstration sewer system over a period of ten years after the system was completed. Evaluation of the demonstration sewer system consists of analysis of wastewater samples of waters carried by the demonstration sewer, laboratory testing of soil samples which have been in contact with the aluminum pipe, evaluation of experimental inlets, sump manholes and other appurtenances, evaluation of the durability of the aluminum material based upon sample coupons extracted from the pipe in place, evaluation of the structural performance of the aluminum pipe in place, and an evaluation of heat shrinkable coupling bands utilized at select locations throughout the project.

SECTION D

OBSERVATION OF THE EFFECTS OF SEWER SEPARATION UPON THE QUALITY OF THE WASTEWATER IN THE EXISTING COMBINED SEWER SYSTEM

The original objective of this phase of the project was to determine the effects of separation of storm and sanitary flows in the combined system upon the quality of those flows. This was to be accomplished by taking wastewater quality samples at strategic locations prior to, during, and subsequent to elimination of roof leaders and elimination of street inlets from the existing combined system and directing them to the new aluminum storm sewer system. This program was initiated and samples of the combined sewage were taken at the three locations indicated in Figure D-1. Observation of the results of the analyses of these samples indicated that the practicality of achieving the intended objective of this phase of the program was doubtful. The quality of the wastewater in the combined sewer system was obviously influenced by many factors such as temperature variation, irregular industrial waste discharges, quantity of flow and other factors which obviously had a much more profound effect upon the parameters analyzed than did the variation of the quantity of wastewater flowing in the combined sewer system as the result of the elimination of downspouts and street inlets. It was decided that, in order to undertake a meaningful program to determine the effects of separation of street inlets and downspouts upon the quality of the combined sewerage, it would be necessary to monitor the combined sewer system on a continuous and extensive basis far beyond the scope of what was originally intended as part of this project. Construction of the aluminum demonstration storm sewer affected the quantity of flow during rainfall periods in a very extensive portion of the combined sewer system within the City of LaSalle. This effect was achieved at a relatively slow rate over an extended period of time (approximately two years) which did not allow for comparison of wastewater quality results on a "combined sewer system" versus a "separated system" within a reasonable period of time. The sampling and analysis requirements for meaningful results under those conditions would have been extremely expensive and it was felt that that type of program would not be justified from an economic standpoint because of the questionable validity of the results and the rather indirect relationship of those results to the construction and technical evaluation of an aluminum storm sewer system. It was felt that a more meaningful approach to wastewater quality would be to place more emphasis upon wastewater sampling in the demonstration aluminum storm sewer during the 10 annual inspection tours.

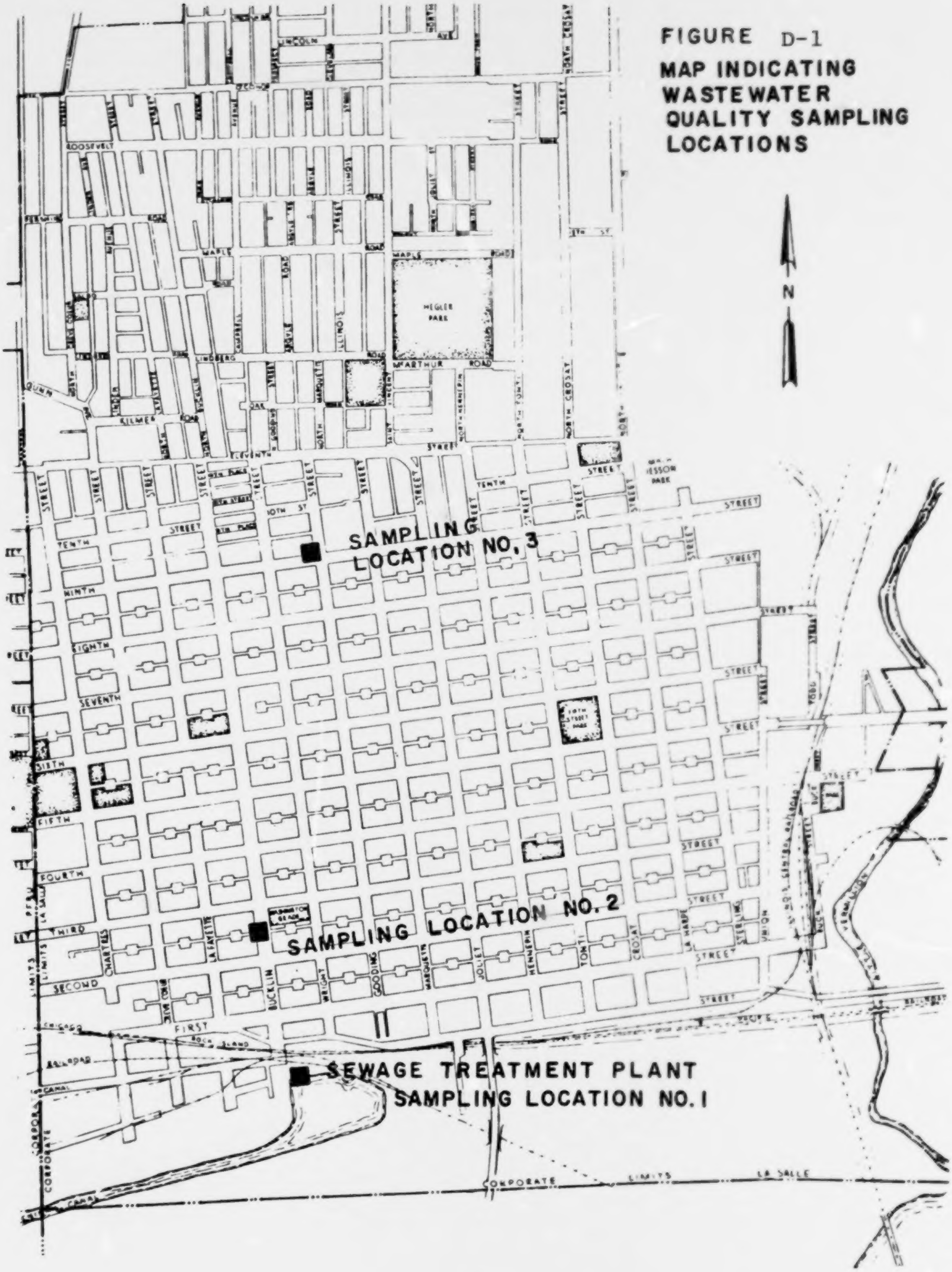

FIGURE D-1
MAP INDICATING WASTEWATER QUALITY SAMPLING LOCATIONS

N
SAMPLING LOCATION NO. 3
SAMPLING LOCATION NO. 2
SEWAGE TREATMENT PLANT
SAMPLING LOCATION NO. 1
HEGLER PARK
MAPLE
McARTHUR ROAD
ROOSEVELT
LINCOLN
GILMER
ELEVENTH
TENTH
NINTH
EIGHTH
SEVENTH
SIXTH
FIFTH
FOURTH
THIRD
SECOND
FIRST
STREET
CHARTRES
LA FAYETTE
BUCKLIN
WRIGHT
GOODING
MARQUETTE
JOLIET
HENNEPIN
TONTI
CROSAT
LA HARPE
STERLING
UNION
NORTH CROSAT
CORPORATE LIMITS LA SALLE
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CANAL

SECTION E

OBSERVATION OF EFFECTS OF SEWER SEPARATION UPON THE QUANTITY OF THE WASTEWATER IN THE EXISTING COMBINED SEWER SYSTEM

PROCEDURE

A continuous recording flow measuring device was installed in a specially constructed manhole in the existing combined sewer system at the location indicated in Figure E-1. This location was selected because the entire combined sewer system tributary to this point would be subjected to removal of all street inlets as a result of the demonstration storm sewer construction. The purpose of the continuous recording flow measuring device was to continuously record flows in the combined sewer system prior to separation and subsequent to various phases of separation during construction and to compare these flows in order to determine the effects of the quantity of sewerage flowing in the combined sewer system as a result of separation. Also, in conjunction with this phase of the project, records of the temperature and rainfall were maintained in order to correlate the sewerage flows in the combined sewer system with freeze-thaw cycles and amount of rainfall for the corresponding periods of time.

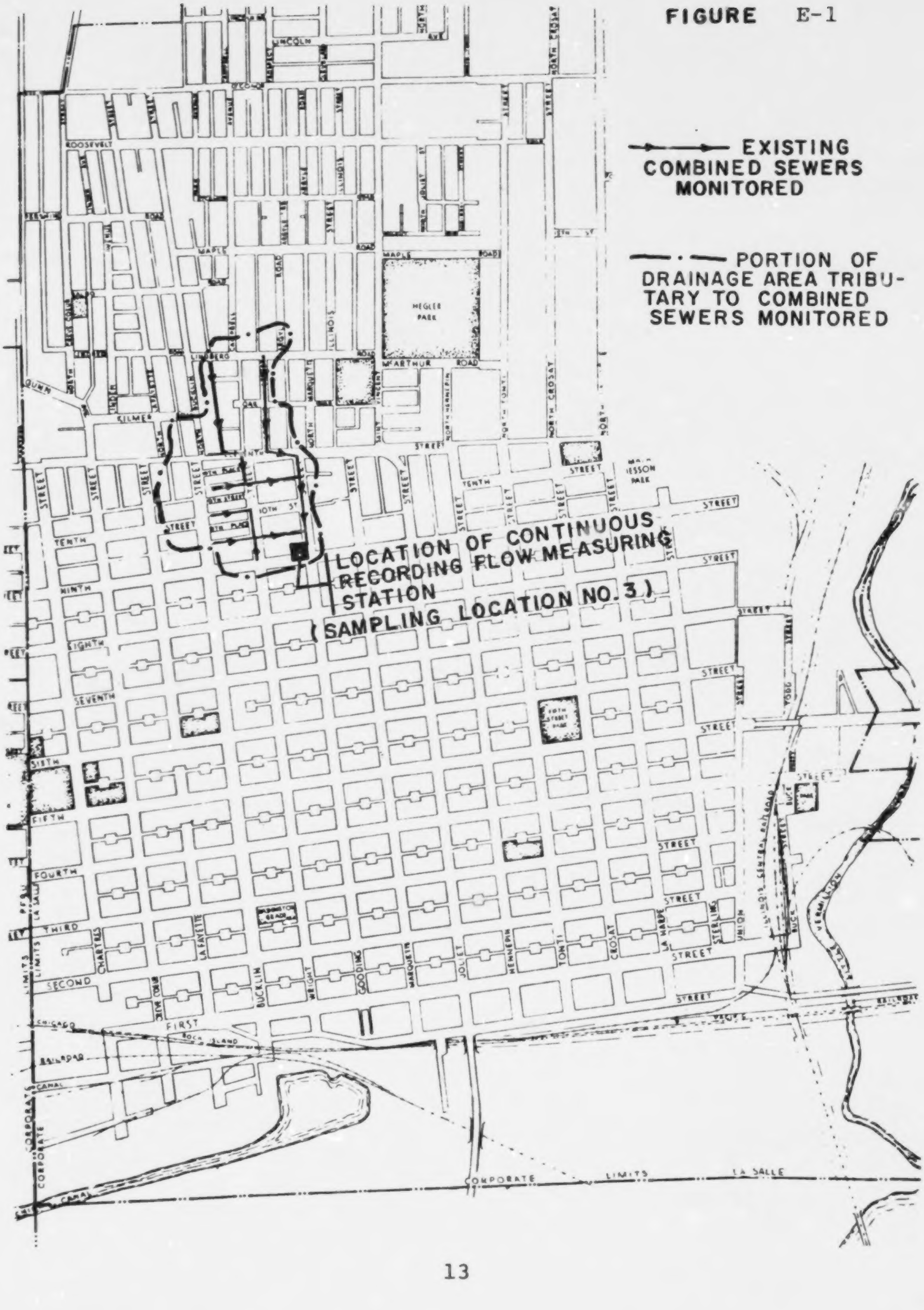
RESULTS

The results of the rainfall records, temperature records, and sewerage flows obtained at the continuous recording flow measuring device are indicated in Figures E-2 through E-17. These figures represent data collected relative to wastewater quantity determinations in the portion of the combined sewer system tributary to the continuous recording flow measuring device.

DISCUSSION OF RESULTS

Observation of the results indicates that total daily flows in the combined sewer system increase somewhat proportionately to the amount of recorded rainfall for the period March 15, 1971 through the latter part of April, 1973. This is the period of time when no demonstration storm sewers were constructed in the geographic area tributary to the combined sewer being monitored at the Northwest corner of 9th and Gooding Streets by the continuous recording flow measuring device. Since construction of the demonstration aluminum storm sewer began at the outfall end of the total system in the Southern portion of the City, the aluminum storm sewers designed to remove surface water from the area tributary to the continuous recording flow measuring device were not begun until the total system progressed to this general location. Construction of these sewers began in about the latter part of April of 1973. (See Figure E-12). Observation of Figures E-2 through E-17 indicates that after the latter part of April 1973, the total daily flow recorded during rainfall periods was significantly less as construction of the demonstration sewer in this area progressed. The demonstration aluminum storm sewer construction to serve this area was completed during the latter part of November of 1973. Observation of Figures E-2 through E-17 indicates that during the month of January and some periods during February and March of 1974 noticeable increases in the volume of flow occurred. Investigation of this situation indicated that a new house was constructed on Oak Road between Bucklin Street and North Gooding Street. The existing combined sewer in that area was excavated and utilized as an area drain during the construction of the house. That situation has since been corrected. Analysis of the data presented indicates that the majority of flow increase during rainfall periods is contributed by surface runoff collected by street inlets. When these direct connections were eliminated by the construction of the demonstration aluminum sewer, the total daily flows during rainfall periods decreased substantially. However, noticeable slight increases continue to occur during rainfall periods. This is undoubtedly the result of non-eliminated downspout connections and foundation drain connections which were not eliminated as part of this project. Because of the high costs and necessity of entering private property further detailed studies of the existing sewer system in the City of LaSalle have been completed in the form of a Sewer System Evaluation Survey funded in part by the State of Illinois Environmental Protection Agency as part of a total Facilities Plan relative to water pollution control. The purpose of this study was to determine the most cost-effective method of eliminating excessive infiltration/inflow in the existing combined sewer system. Conclusions drawn in the Infiltration/Inflow Analysis indicate that excessive infiltration/inflow (primarily inflow in the form of surface runoff) exists in the existing sewer system and that the most cost-effective method of elimination at this location, is to provide practical separation of storm and sanitary sewers in conjunction with some additional treatment. This allows for the use of the existing combined sewers to function as adequate sanitary sewers free of excessive infiltration/inflow during rainfall periods.

FIGURE E-1


EXISTING COMBINED SEWERS MONITORED
PORTION OF DRAINAGE AREA TRIBUTARY TO COMBINED SEWERS MONITORED
LOCATION OF CONTINUOUS RECORDING FLOW MEASURING STATION (SAMPLING LOCATION NO. 3)
LINCOLN
ROOSEVELT
MAPLE
HEGLER PARK
MCARTHUR ROAD
GILMER
LINDBERG
ILLINOIS
NORTH CROSAT
TENTH
NINTH
EIGHTH
SEVENTH
SIXTH
FIFTH
FOURTH
THIRD
SECOND
FIRST
CHARTRES
LA FAYETTE
BUCKLIN
WRIGHT
GOODING
MARQUETTE
JOLIET
HENNEPIN
TONTI
CROSAT
LA HARPE
STERLING
UNION
VERMILION
CHICAGO ROCK ISLAND RAILROAD
ILLINOIS CENTRAL RAILROAD
CANAL
CORPORATE LIMITS LA SALLE
STREET

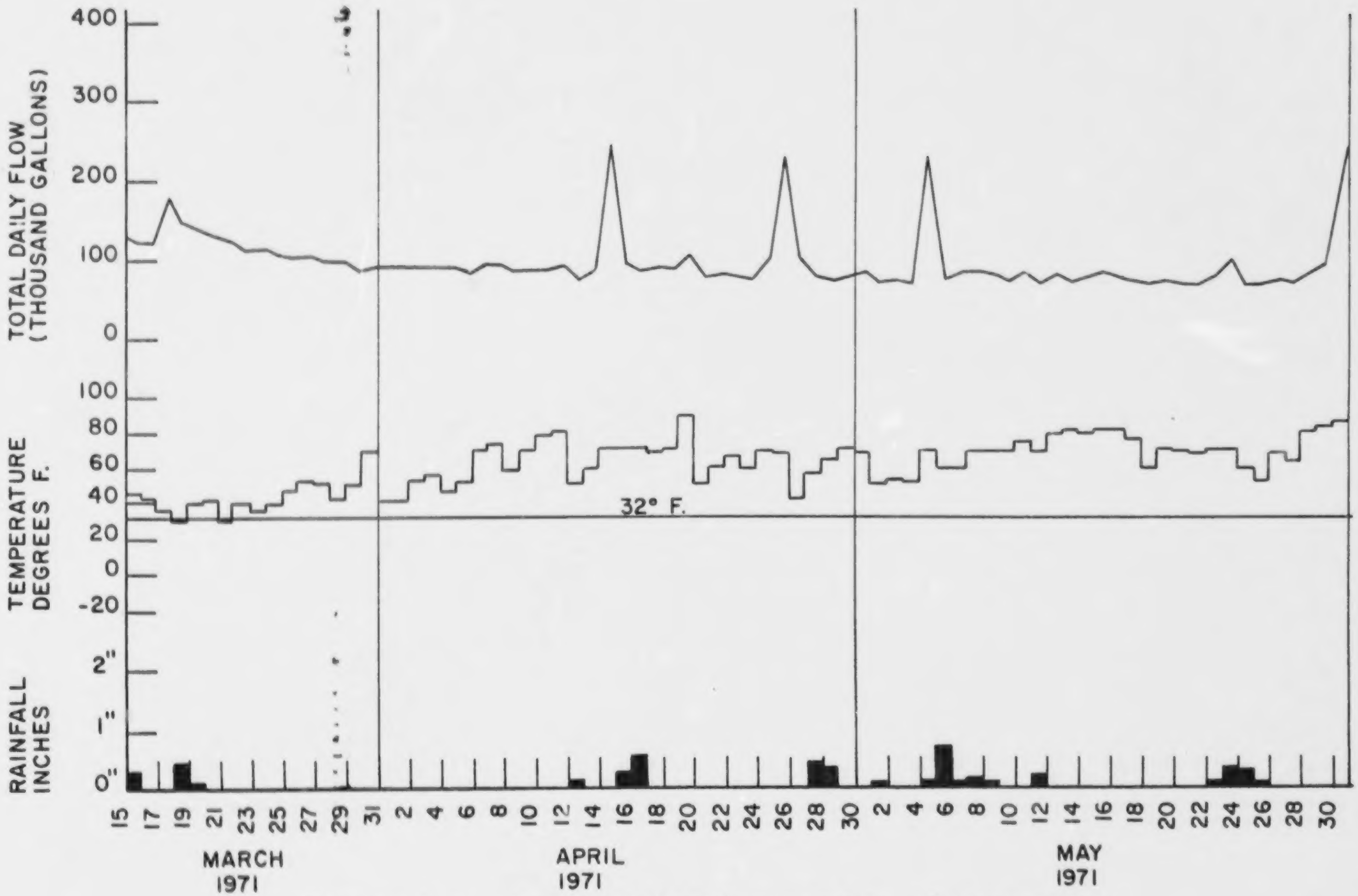


Figure E-2. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

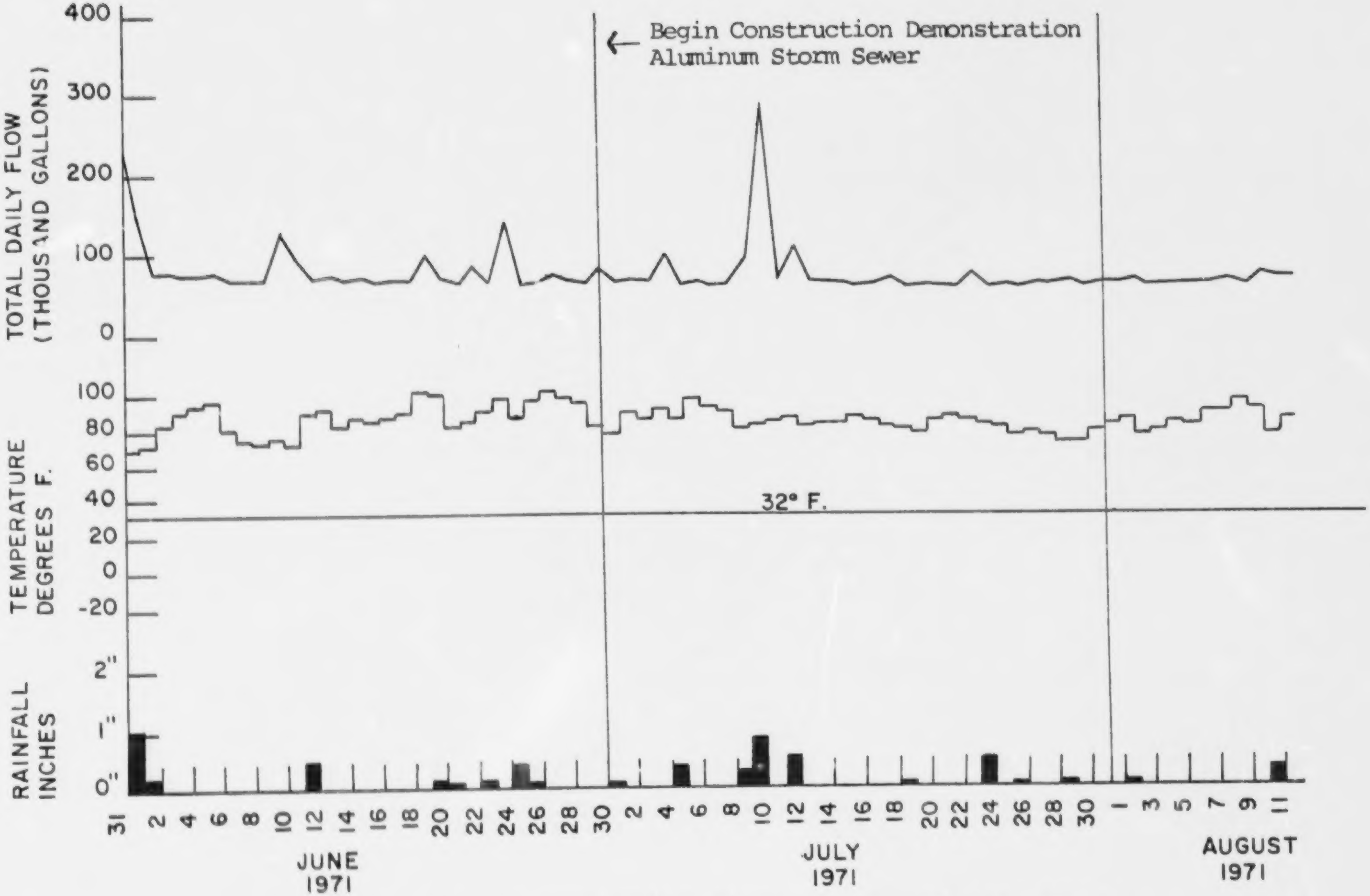


Figure E-3. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

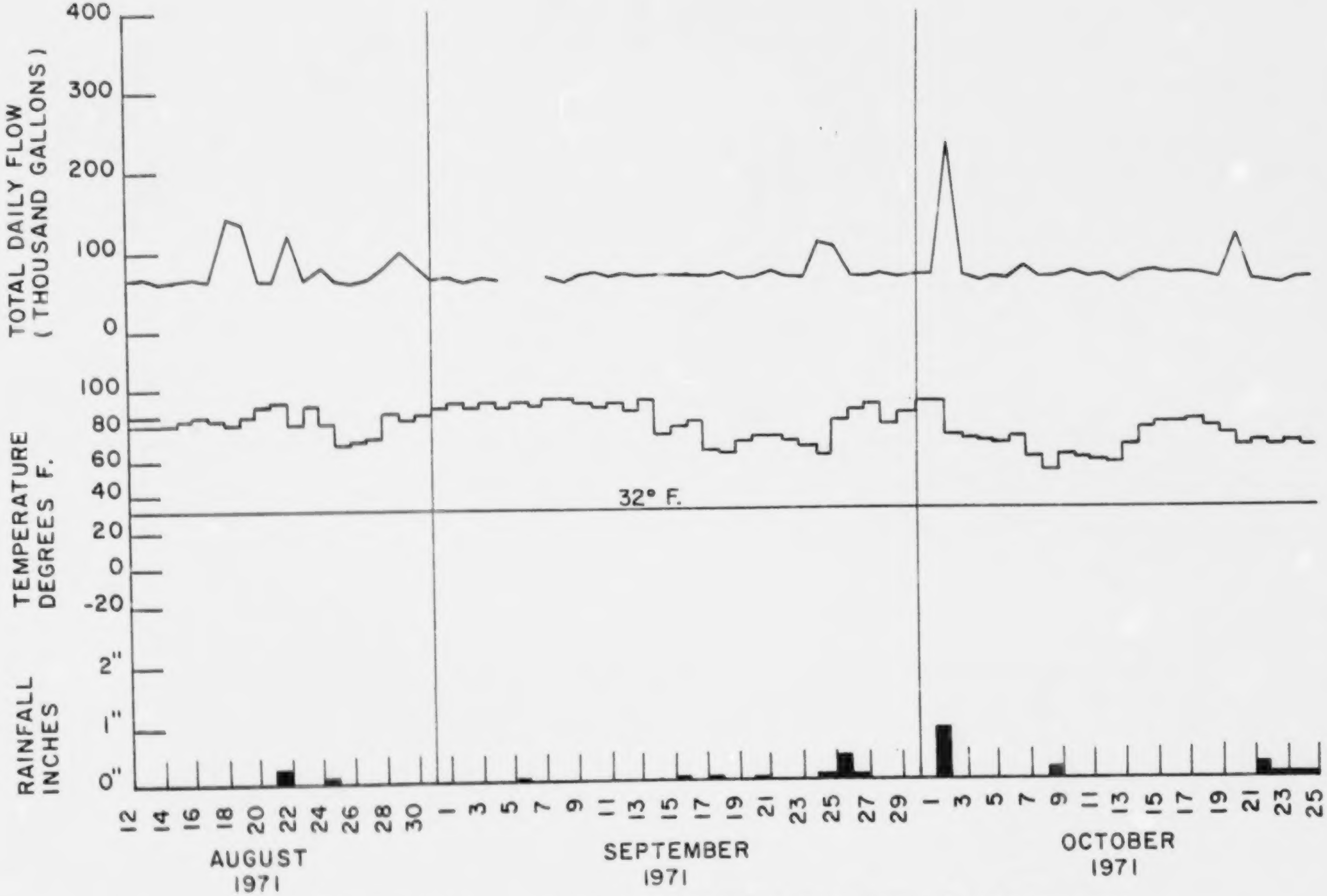


Figure E-4. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

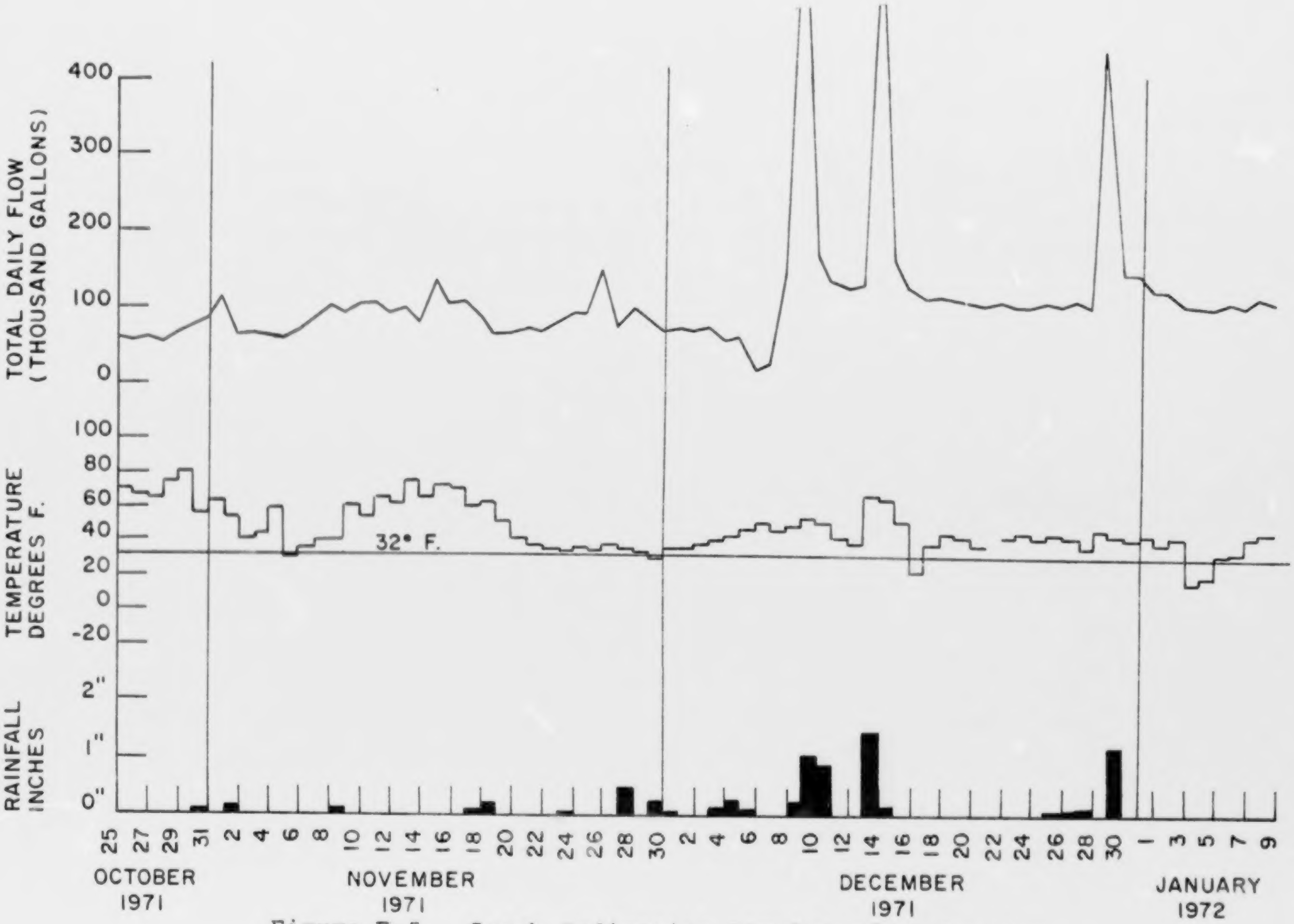


Figure E-5. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Flow Measuring Station

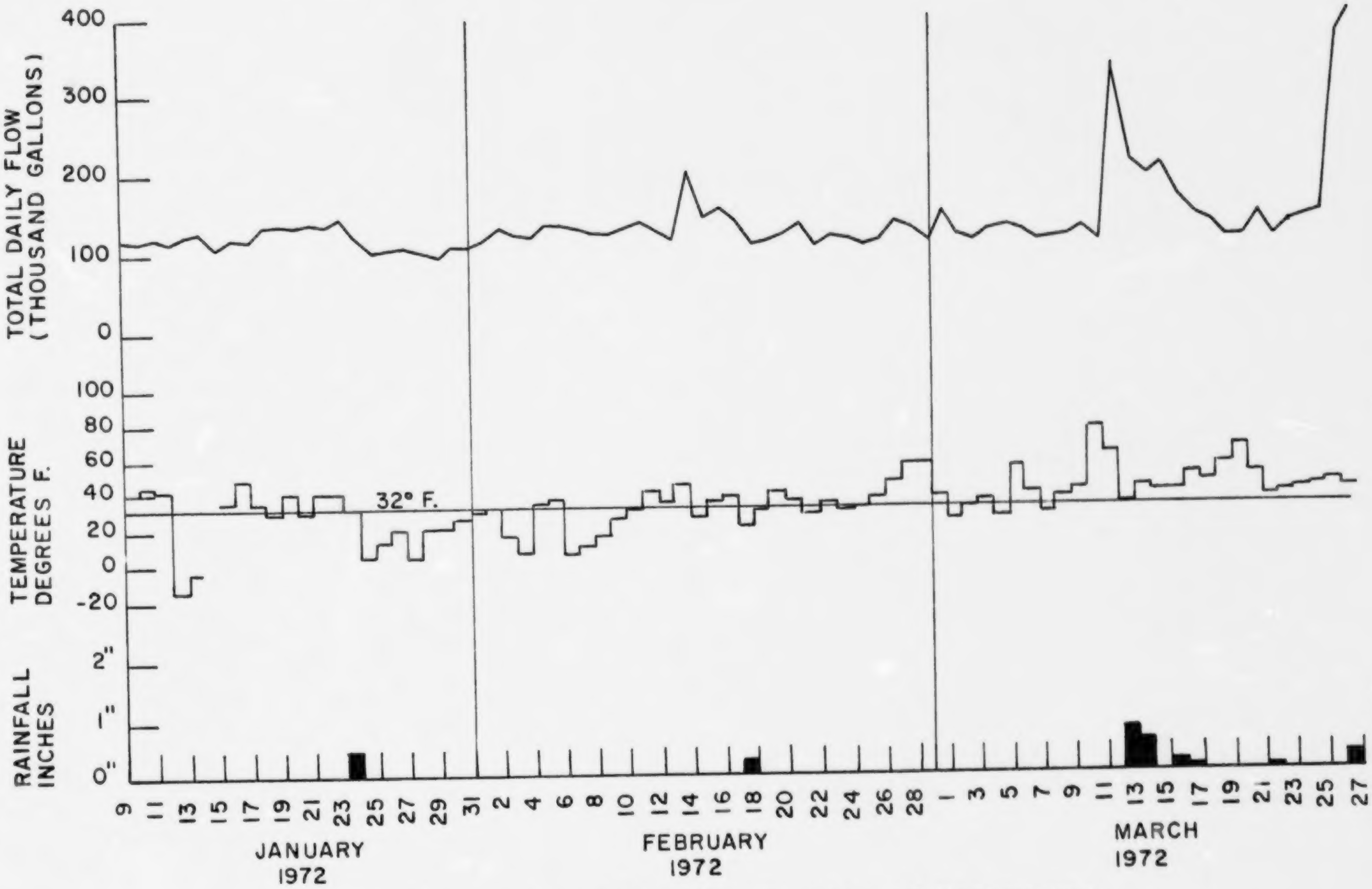


Figure E-6. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

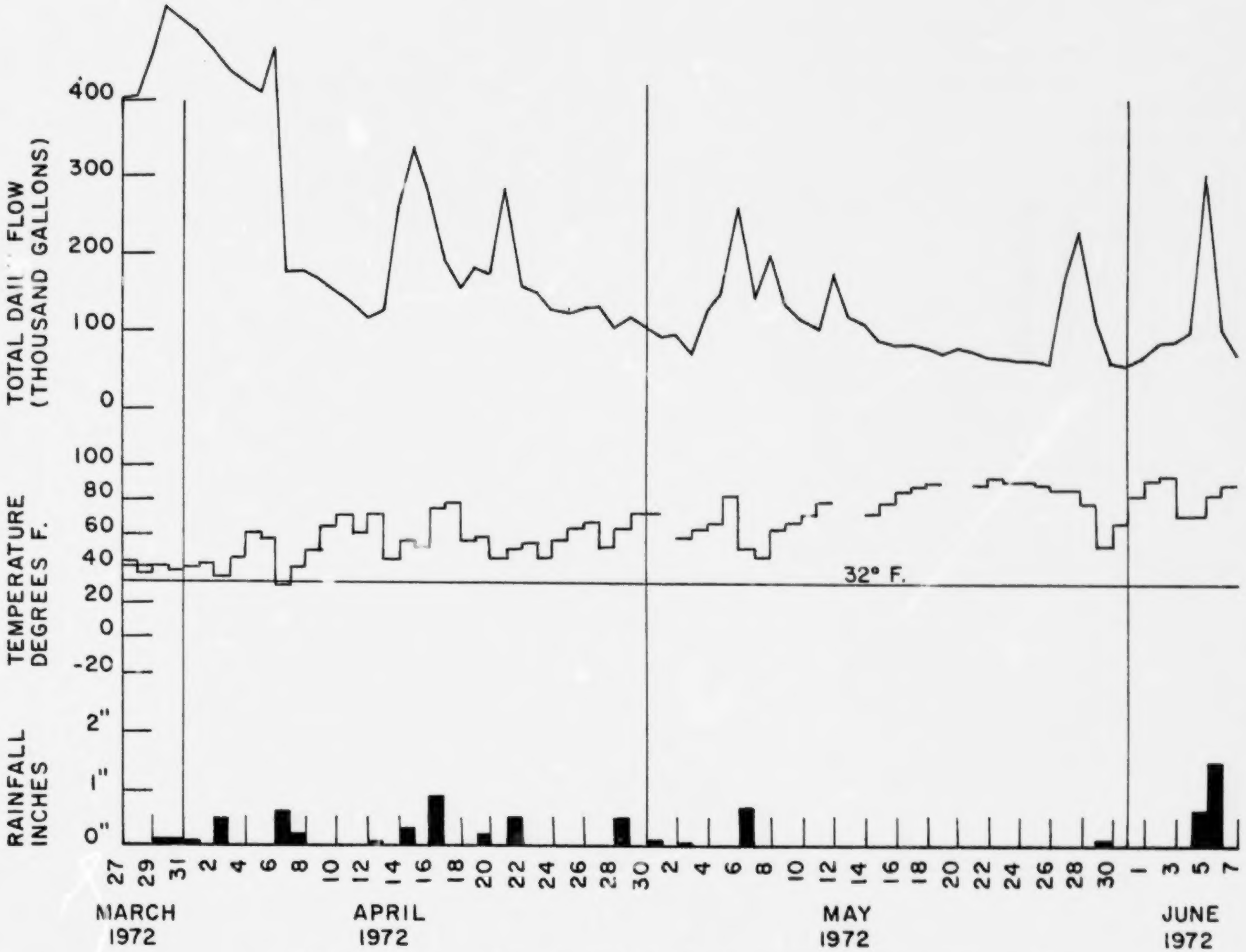


Figure E-7. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

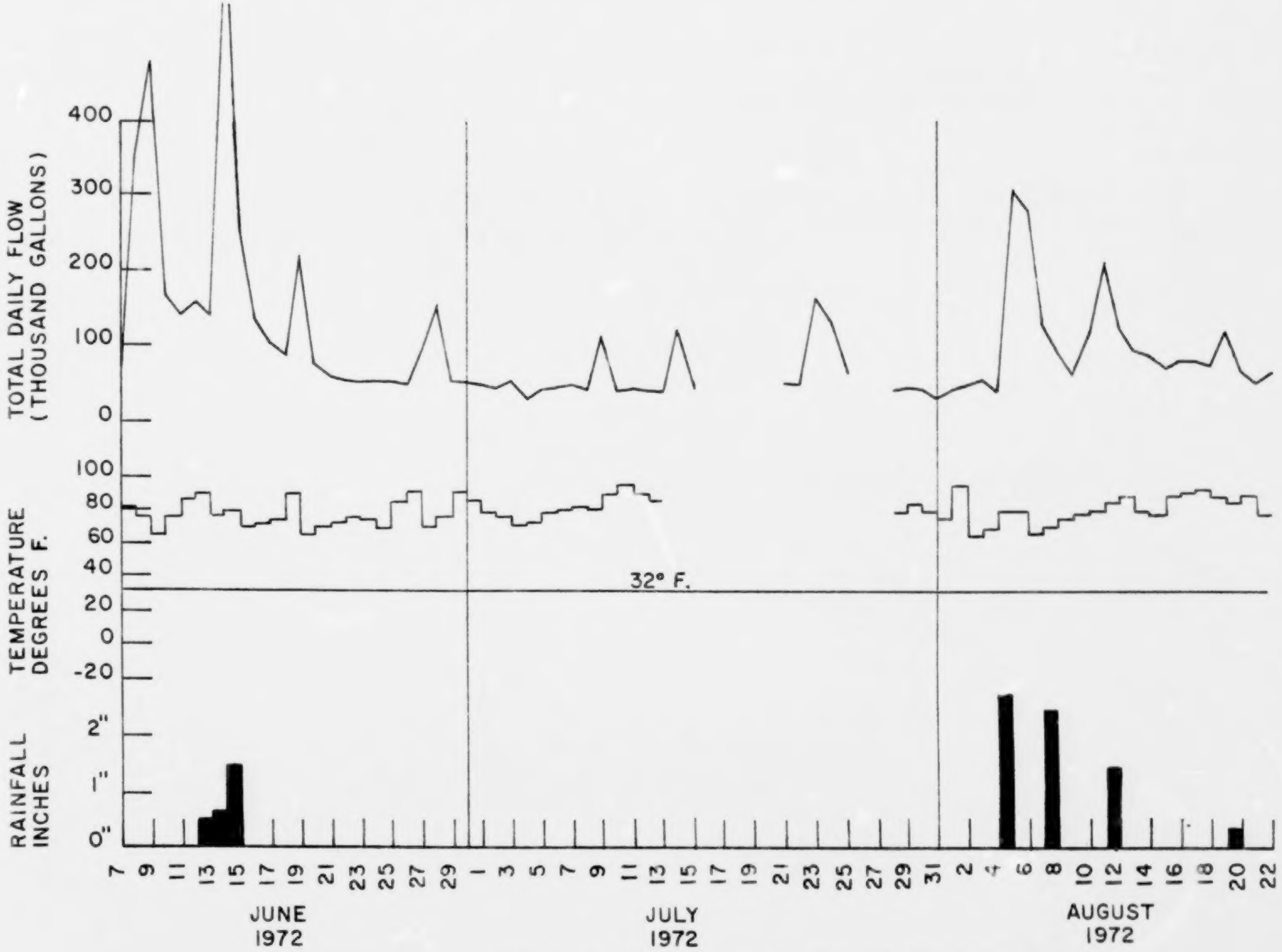


Figure E-8. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

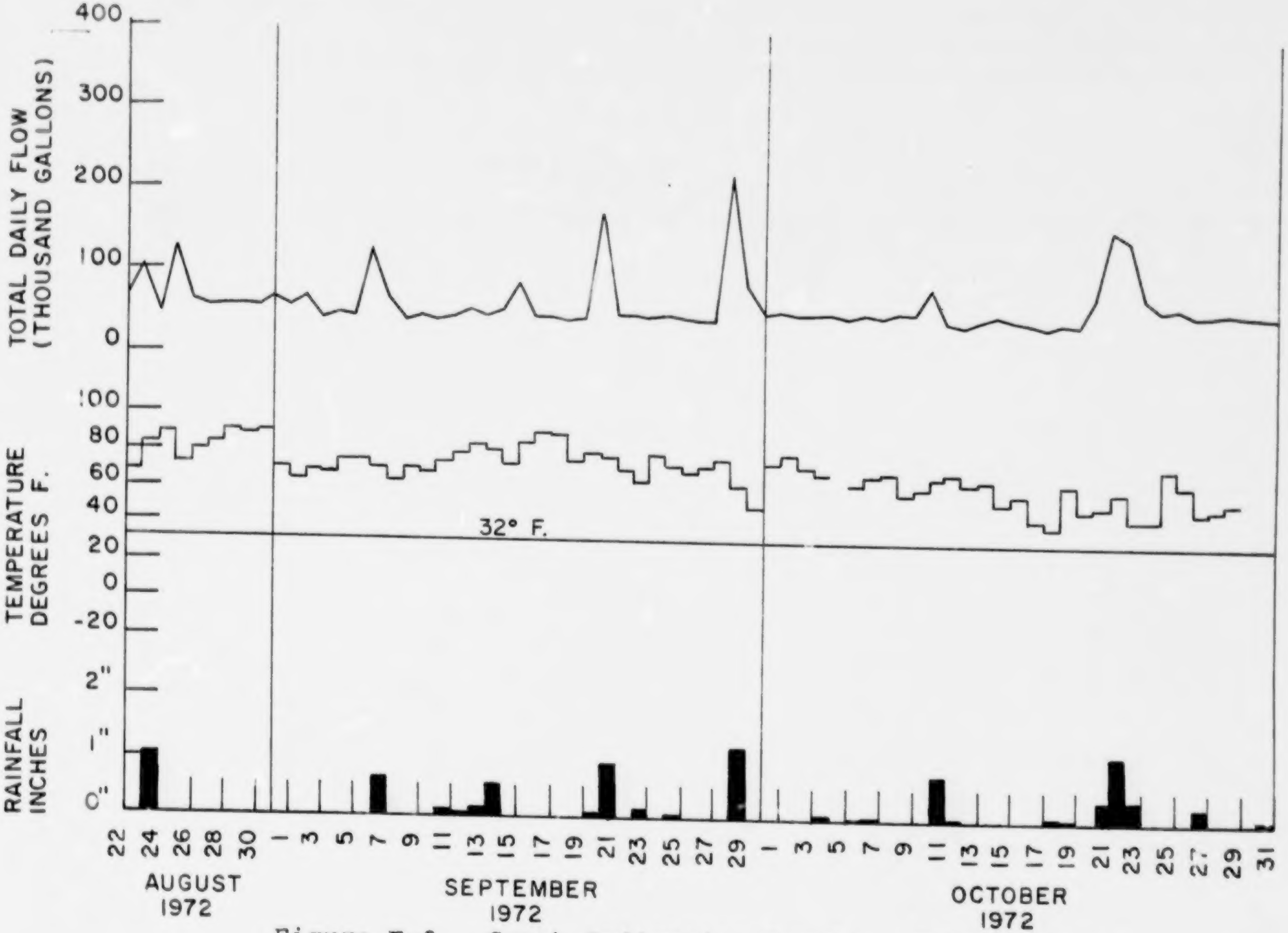


Figure E-9. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

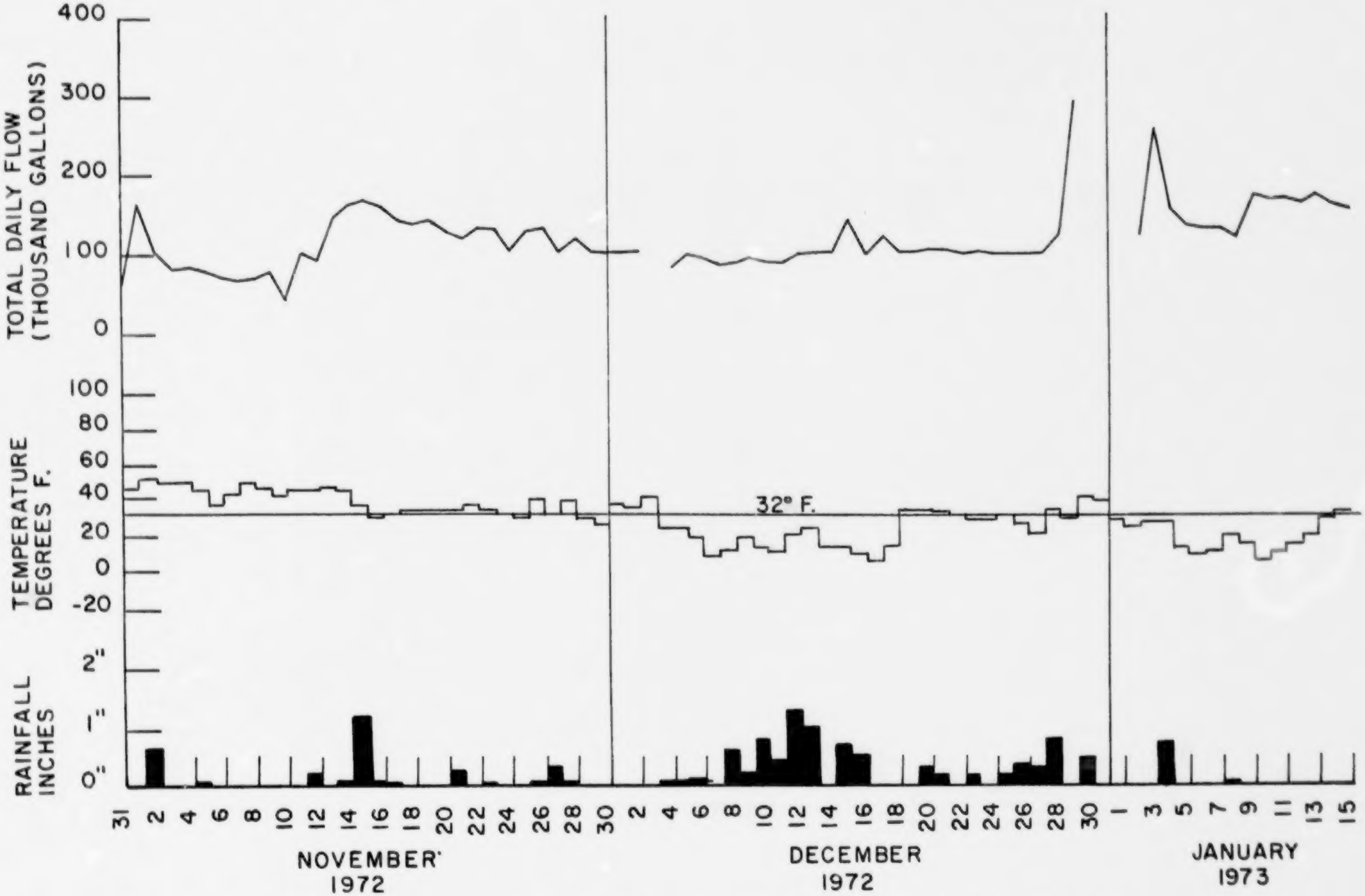


Figure E-10. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

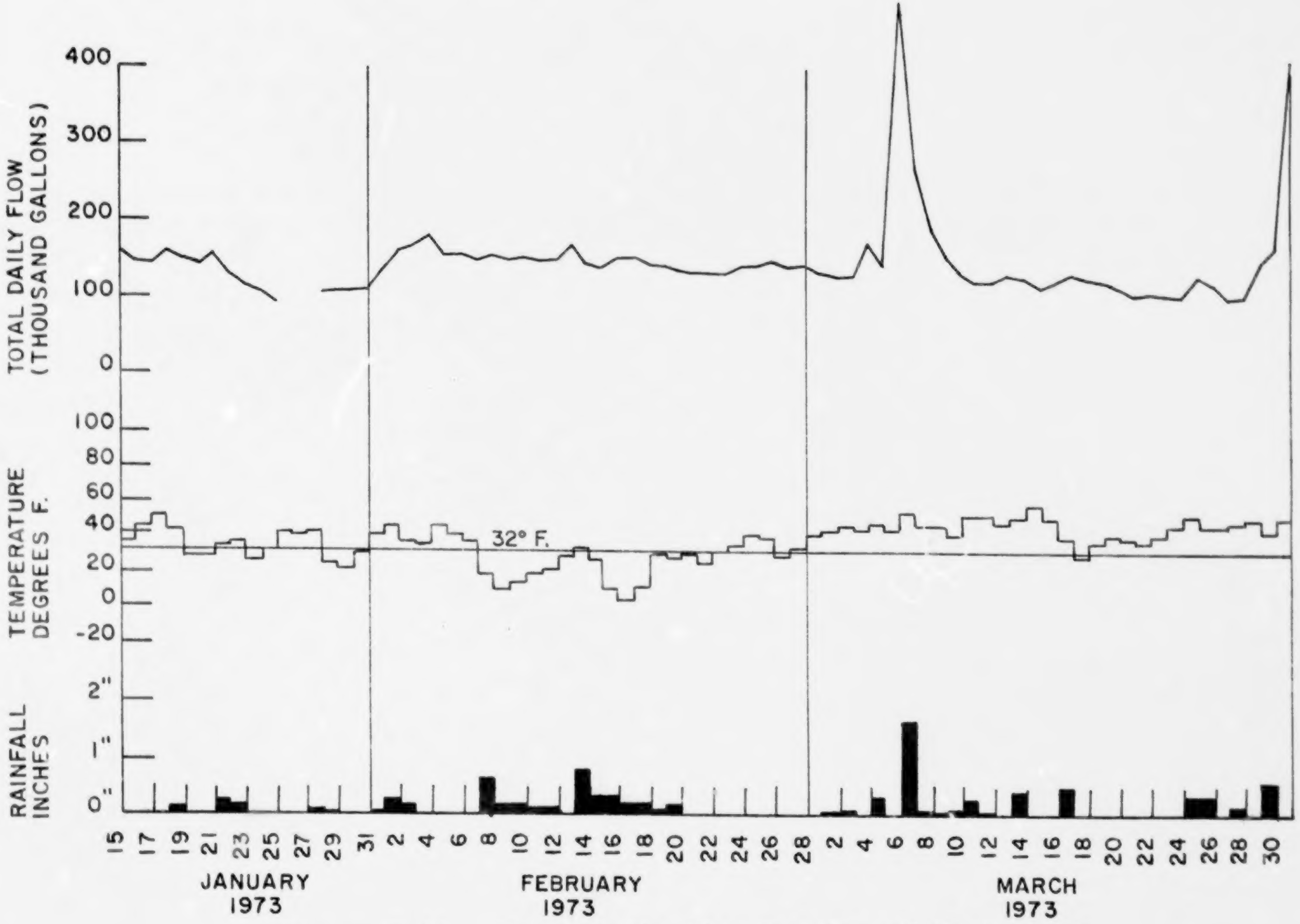


Figure E-11. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

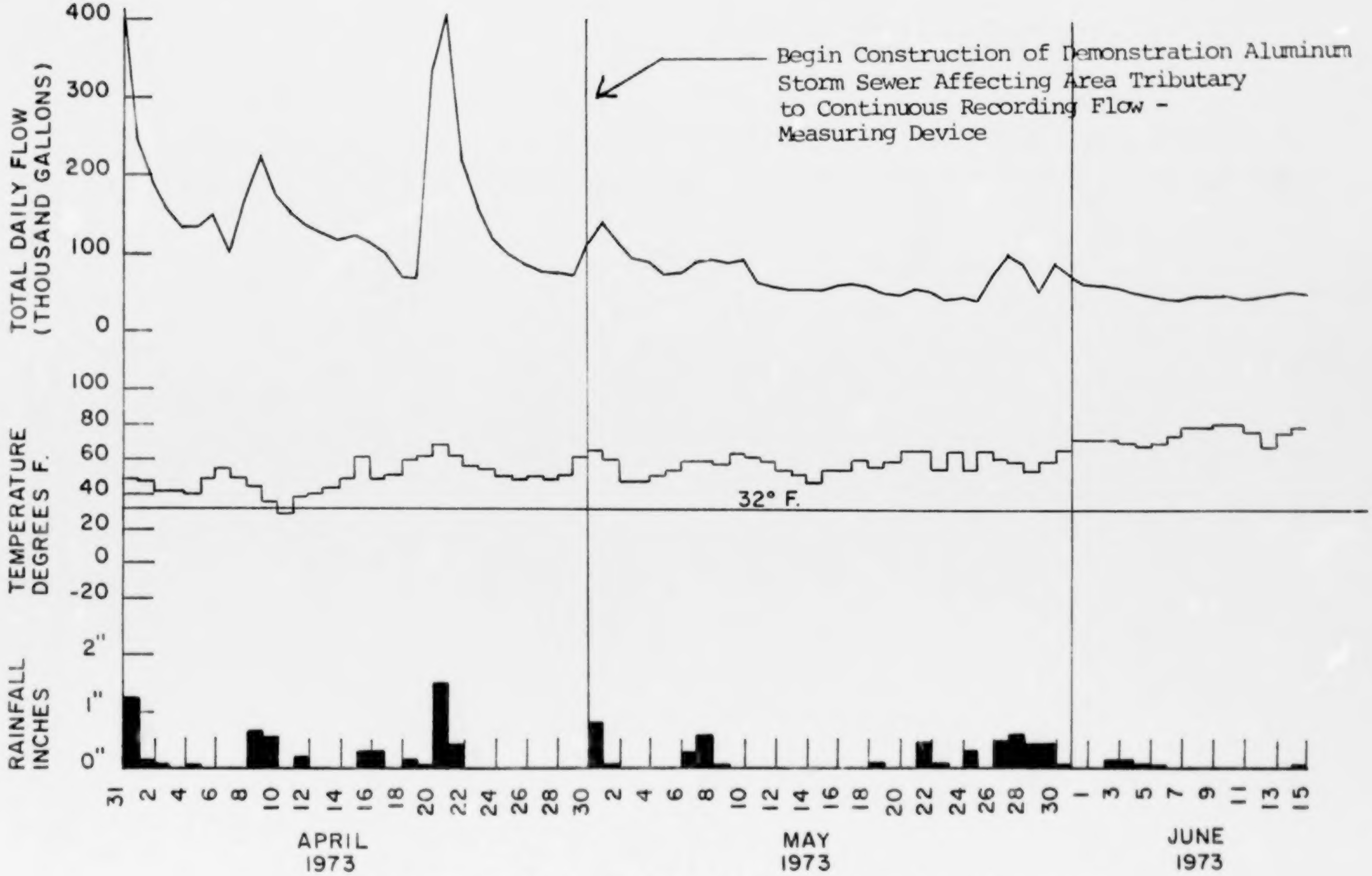


Figure E-12. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

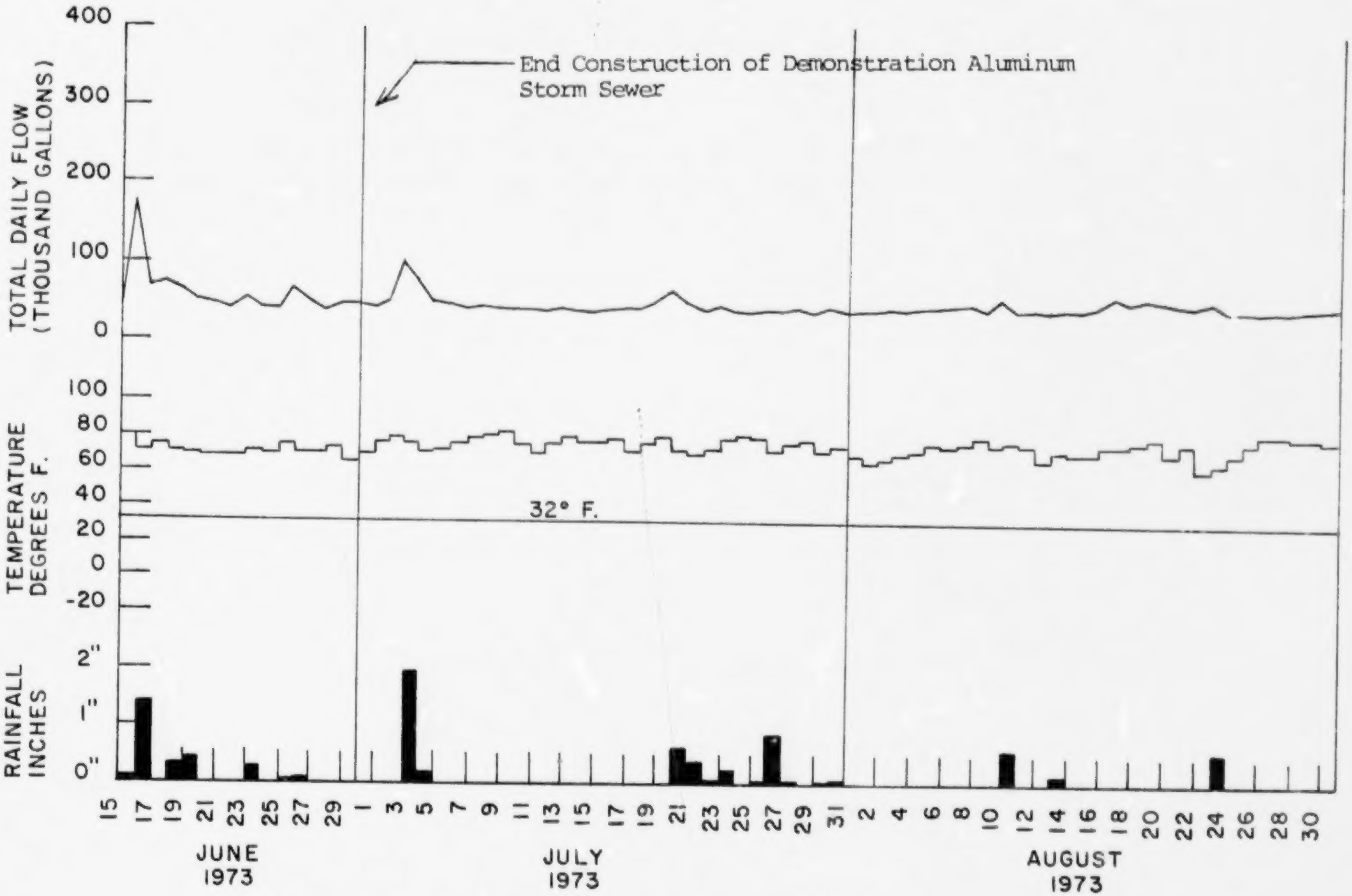


Figure E-13. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

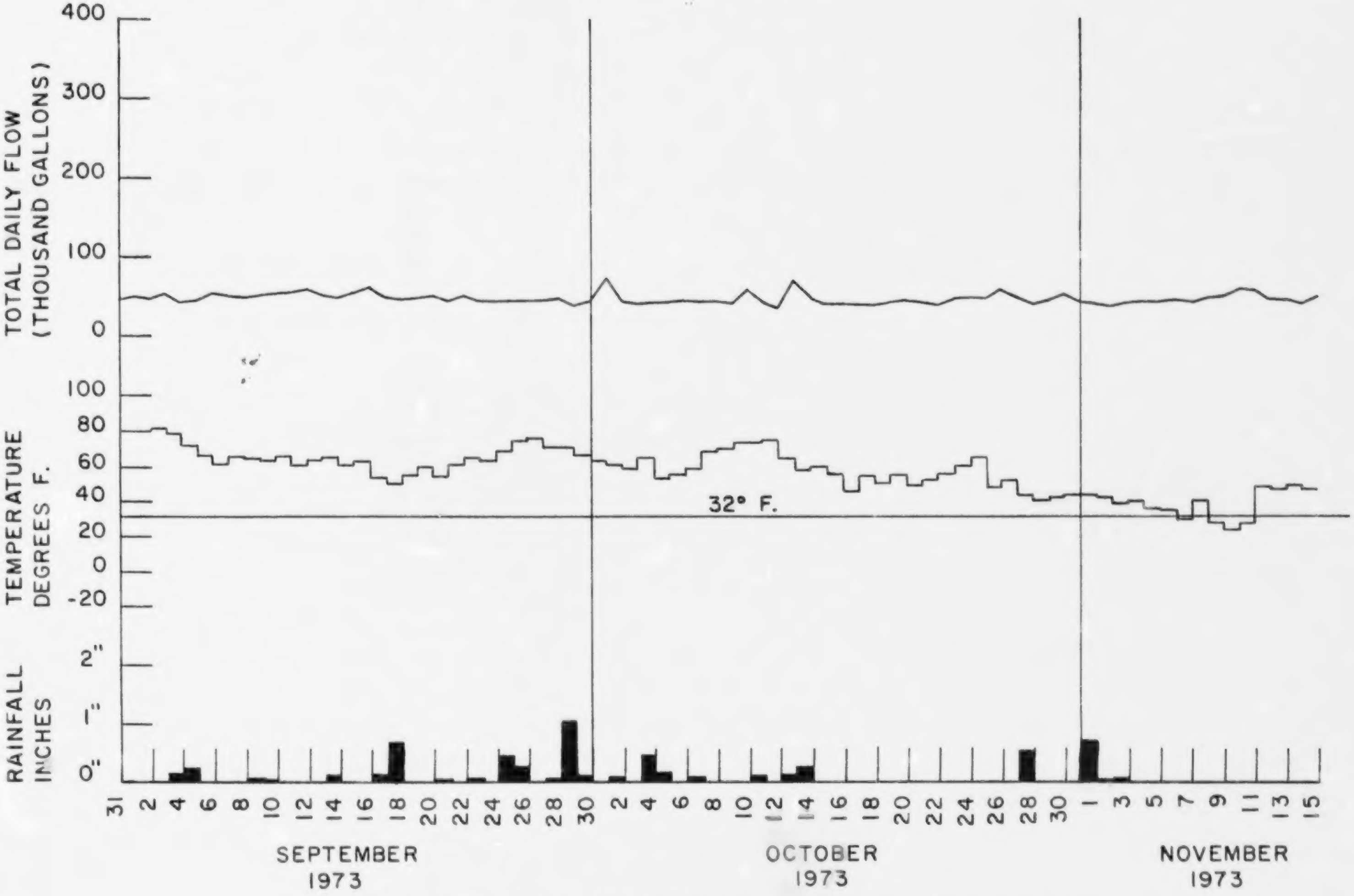


Figure E-14. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

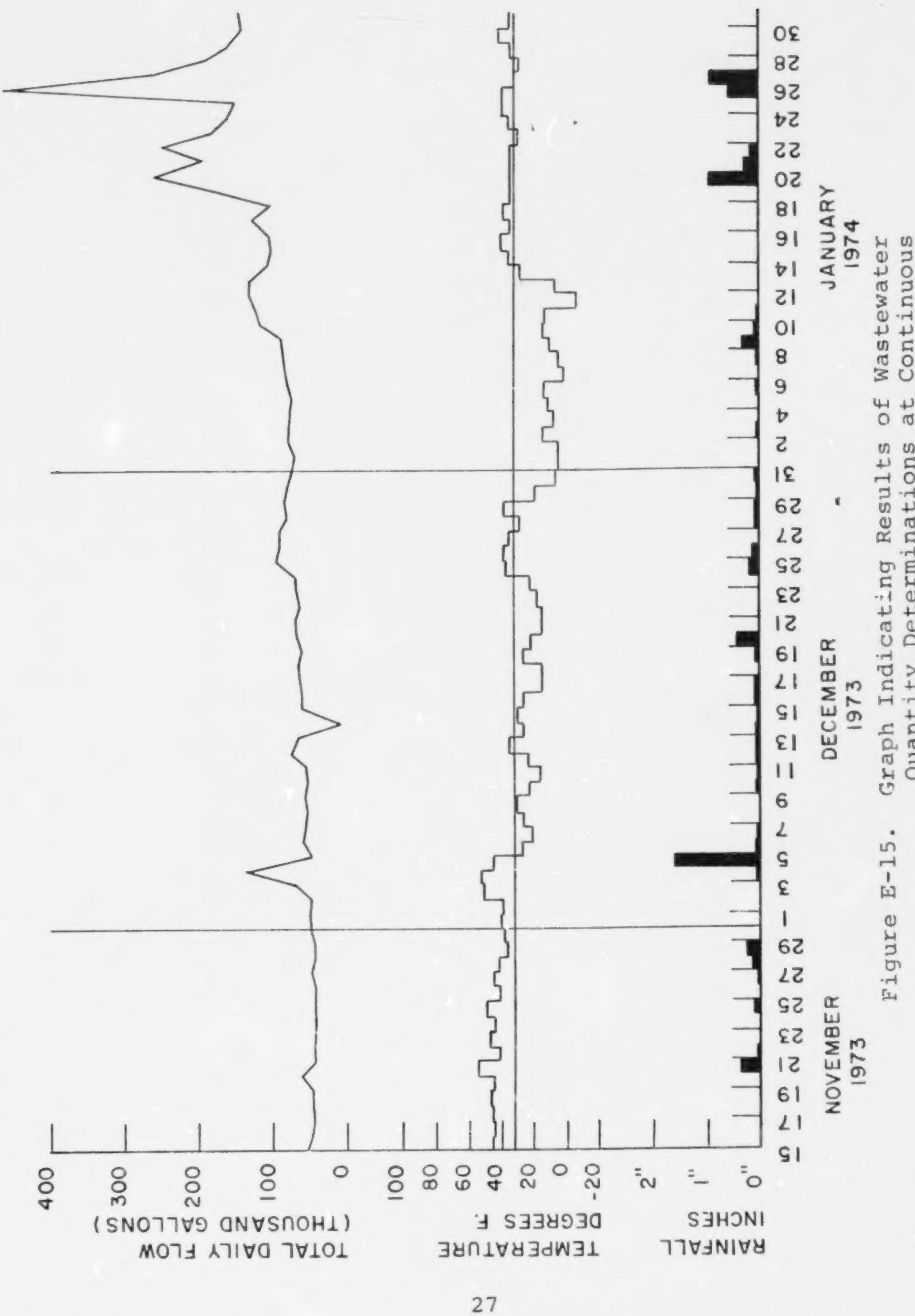


Figure E-15. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

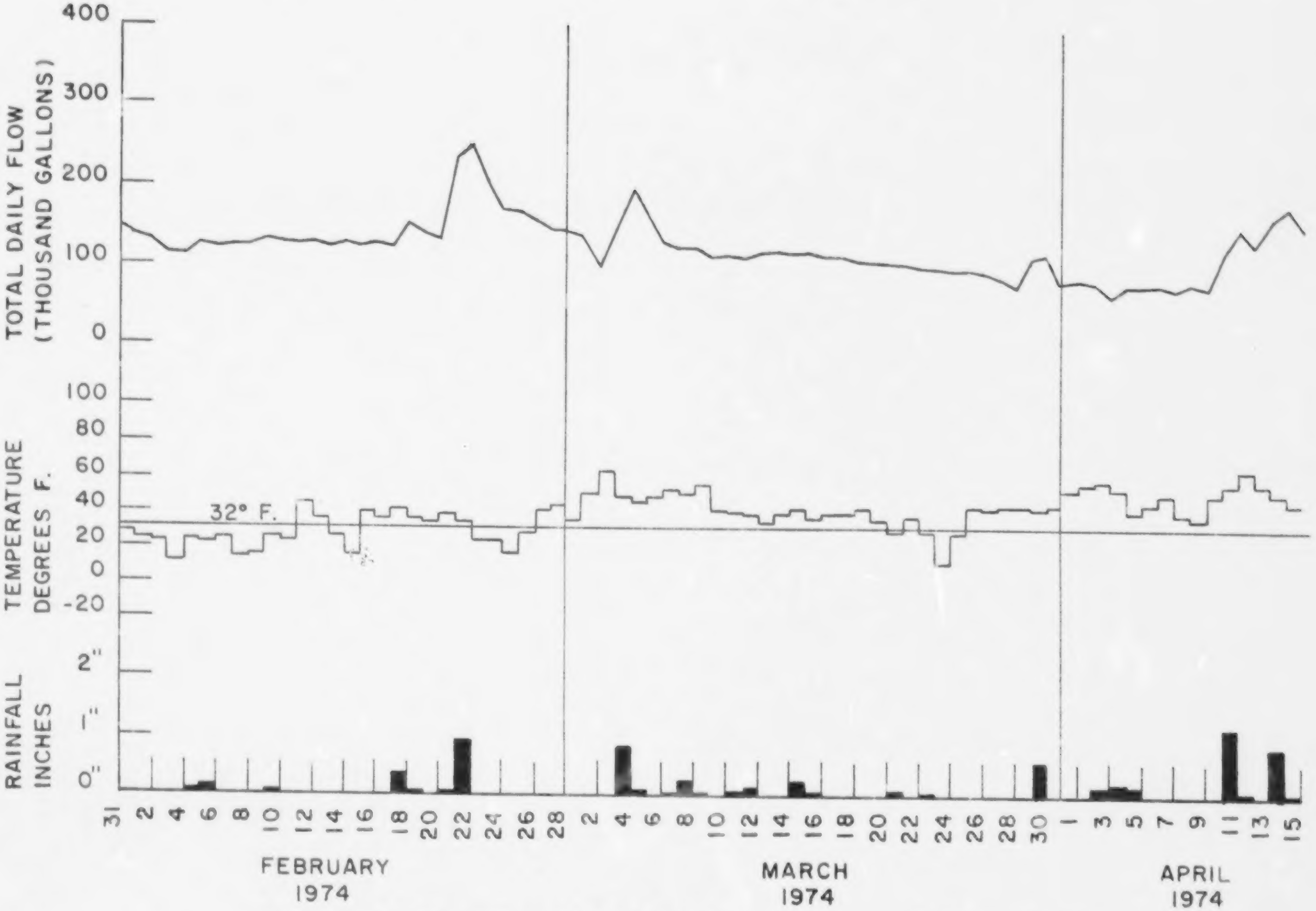


Figure E-16. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

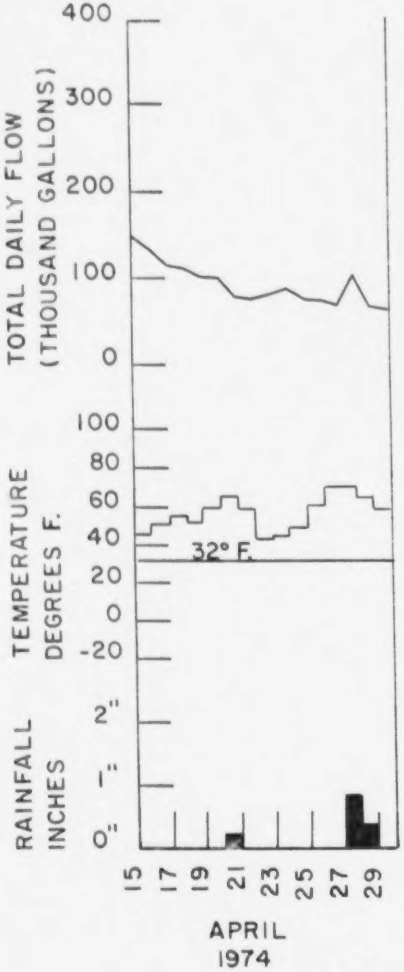


Figure E-17. Graph Indicating Results of Wastewater Quantity Determinations at Continuous Recording Flow Measuring Station

SECTION F

LABORATORY TESTING OF ALUMINUM PIPE

This major phase of the project involved laboratory testing of both helical and annular corrugated aluminum pipe flowing full in a laboratory to determine the friction factors and to make qualitative observations of the pipe joint characteristics. Proposals to perform this work were sought from the St. Anthony Falls Hydraulic Laboratory at the University of Minnesota in Minneapolis, Minnesota, the Department of the Army Waterways Experiment Station Corps of Engineers, Vicksburg, Mississippi, and the Department of the Army Division Hydraulic Laboratory North Pacific Division Corps of Engineers, Bonneville, Oregon. The St. Anthony Falls Hydraulic Laboratory submitted the lowest bid to perform this work and was subsequently employed for this purpose. The procedure, results and conclusions of those tests are included in the appended Project Report No. 121 entitled"Further Studies of Friction Factors for Corrugated Aluminum Pipes Flowing Full"by Edward Silberman and Warren Q. Dahlin of the University of Minnesota, St. Anthony Falls Hydraulic Laboratory. Select protions of that report are reproduced as follows:

> CONCLUSIONS
>
> The experiments described in this report have been conducted using corrugated aluminum pipes flowing full. The measurements were made following an entry region of 20 or more pipe diameters, and although this distance appears to be sufficient, it is not known whether this is a minimum distance for fully developed flow. Measurements were made under laboratory conditions with pipe carefully aligned and joints carefully made so as to avoid introducing additional roughness. The water used in the tests carried a light load of sand, mostly as suspended load, from the Mississippi River. No significant amount of sand was found in the pipes after the flow was shut down; it is not believed that the sand affected the results.
>
> Under these conditions, the following statements can be made regarding friction factors:

(1) Aluminum annular riveted pipes with 6 in. by 1 in. corrugations have the same friction factors for fully rough flow as do steel riveted pipes with 2-2/3 by 1/2 in. corrugations. Empirical formulas including both are

$$f = 0.122\ D^{-0.41}$$

and $$n = 0.0257\ D^{-0.042}$$

where D is the inside diameter measured in feet. Field assembled and bolted pipes have materially greater friction factors because of both the larger relative depth of corrugations and the presence of bolt heads and rougher joints within the pipes.

(2) Helical pipe has lesser friction factors than similar annular pipe of the same diameter; the smaller the helix angle, the less the friction factor. Empirical formulas including both annular and helical pipes of both aluminum and steel are

$$f = 0.945 \times 10^{-8}\ \frac{\theta^{3.64}}{D^{0.41}}$$

and $$n = 0.713 \times 10^{-6}\ \frac{\theta^{1.82}}{D^{0.042}}$$

where θ is the helix angle (measured from the pipe axis) in degrees and D is the inside diameter measured in feet. These formulas are limited to the range of the data available, $52\text{-}1/2 \leq \theta \leq 90$. There appears to be little effect of relative roughness on helical pipe friction factors.

(3) The thermoplastic sealant provided for the aluminum pipe tests makes a very effective field seal at the pipe joints. However, in the laboratory tests without earth backfill around the pipes, it was found necessary to reinforce the joint seals with corrugated metal bands to prevent the seals from opening due to pressure and vibration. The bands materially increased the rigidity of the pipe line. (Plain metal bands did not protect the seal as well as corrugated bands)

Using corrugated metal bands it was also possible to seal the joints with bands of rubber gasket material placed cold, but several trials were necessary at each joint before a tight seal could be made.

(4) The factory-assembled pipes, especially the helical pipes which contained sealant in the spiral joints, were reasonably tight against leakage even without backfill. The field assembled, bolted pipe leaked badly even though sealer strips were used along the bolt rows.

(5) In factory assembled pipe, care should be taken to avoid unnecessary joint roughness. Extruding joint sealant from spiral joints on helical pipe, which can introduce roughness, should be avoided.

PIPE CHARACTERISTICS

The St. Anthony Falls Hydraulic Laboratory was engaged by Chamlin and Associates, Inc., of Peru, Illinois, to determine the friction factors for fully developed flow in several sizes of annular and helical corrugated pipes flowing full and to make qualitative observations of the pipe joint characteristics. The pipes, which ranged in diameter from 12 to 66 inches, are being considered for use in a demonstration storm sewer project located in LaSalle, Illinois, which is being supported in part by the Office of Water Quality of the U.S. Environmental Protection Agency. The pipe characteristics are given in Fig. 1. (of the report).

Pipe for the tests was provided by two suppliers, Kaiser Aluminum and Chemical Sales, Inc., and the Reynolds Metals Company. Except for the 66 in. bolted pipe, the pipes were shipped to the laboratory in mostly 40 ft. (a few 20 ft.) lengths to provide a test pipe about 220 ft. in length for the 66 in. and 48 in. sizes and about 100 ft. in length for the 24 in. and 12 in. sizes. The 66 in. bolted pipe was shipped in 4.5 ft. wide semi-circular pieces and assembled into a 220 ft. length in the Laboratory's main test channel. The pipes were inspected upon receipt to insure against leakage and to get accurate measurements for use in reducing test results. The seams of the factory-assembled pipes had been sealed with sealing compound during fabrication according to standard factory methods.

In some of the helical pipes, considerable sealant had been forced inside the pipe and would have affected the friction factor measurements. The 48 in. and 24 in. helical pipes were thoroughly scraped on the inside by Laboratory personnel. Since it was impossible for a man to enter the 12 in. pipe to scrape it, the first shipment of that size could not be used. It was replaced by a second shipment in which greater care had been taken during manufacture to prevent the sealant from getting inside the pipe.

The helical pipe seams did not leak during the experiments, but some leakage occurred from the annular riveted pipes and considerable leakage occurred from the bolted pipe. Leakage from the 48 in. annular riveted pipes, illustrated in Fig. 4, (Of the Report) was easily stopped by application of silicone cement from outside the pipe. There was more leakage from the 66 in. annular riveted pipe, especially where the transverse and longitudinal seams met, but this was also sealed with silicone cement.

The greatest seam leakage problems occurred with the bolted pipe. The assembly materials included strips of 3M joint sealant tape which were applied over every row of bolt holes, both longitudinally and transversely. Notwithstanding this tape, leakage was severe until it was finally reduced to manageable proportions by inserting a black permagum sealer with a putty knife into all joints from the inside of the pipe. The sealed joints can be seen in the lower photograph of the frontispiece and in Fig. 5. (Of the Report) Figure 5 also shows, incidentally, the roughness of the interior of the bolted pipe. It should be understood that this pipe, like all the pipes under test, was unsupported on the outside; with compacted earth fill around the pipe, the leakage would have been much less. The inside pipe diameter is an important parameter in determining the friction factor, and it was measured carefully. Personnel entered all pipes 24 inches in diameter or larger and measured the actual inside diameters with two sliding bars equipped with verniers (frontispiece). The inside diameter of each pipe was measured every 2 ft. (every 1-1/2 ft. for the bolted pipe) through the test section in both vertical and horizontal directions. Corrugation depths were measured with a depth gauge about every 4 ft., four readings being made at each section. For the 12 in. pipe, the outside diameter and corrugation depths were measured and the inside diameter computed. The average measured values of inside diameter, standard deviation, and corrugation depth are reported in Fig. 1 (of the Report) over the length of pipe used for determining hydraulic grade lines. The helix angle was also measured and is given in Fig. 1 (of the Report); it agreed closely with factory specifications.

SECTION G

DESIGN OF AN INTEGRATED ALUMINUM DEMONSTRATION STORM SEWER SYSTEM AND APPURTENANCES

The entire drainage area tributary to the demonstration storm sewer system was included in a contour map prepared photogrammetically to a horizontal scale of 1-inch equals 100 feet and a vertical contour interval of 2 feet. Exact drainage areas were determined from this contour map and the total system was designed on that basis. Required capacities of storm sewers were determined by utilizing the rational formula for storm sewer runoff. The aerial survey map also provided detailed information with regard to the number of houses, buildings, parking lots, paved areas and all other items having a relatively impervious surface. This allowed for maximum accuracy within the limits of the rational method. Detailed plans and specifications were then prepared utilizing aerial survey strip maps of the various streets along which the storm sewer was to be constructed. The strip maps were prepared photographically to a scale of 1-inch equals 20 feet and the profile of the existing ground were obtained from field elevations. All existing underground utilities of record were located in the field and shown on the plans for location and elevation where available. Sizes and slopes of storm sewer were selected utilizing friction factors obtained from the University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Project Report No. 121 entitled "Further Studies of Friction Factors for Corrugated Aluminum Pipes Flowing Full" by Edward Silberman and Warren Q. Dahlin, which report was prepared as part of this project. The project was divided into a construction division and a materials division with separate bids being taken for both divisions. Aluminum pipe was specified exclusively. Detailed plans and specifications were prepared which plans and specifications designated the trench detail construction, type of bedding and backfill material to be utilized, details of special aluminum structures and appurtenances and the alignment and elevation profiles of the proposed storm sewer lines. A complete soil profile was prepared utilizing soil borings taken along the proposed route of the entire storm sewer system. The soil work was performed by Dr. Robert K. Morse, Engineering Geologist, of El Paso, Illinois. This information was utilized to provide information to prospective bidders with regard to the type of soil to be encountered, as well as to determine the various types of native soil which would be encountered and to make provisions to utilize the various types of native backfill at selected locations so that samples of this backfill could be taken and analyzed as part of the post construction evaluation. Select granular material determined to be non-reactive to the aluminum alloys utilized in the storm sewer material was specified as bedding and backfill for the major portion of the project. Information received from the Aluminum Association indicated that backfill material considered safe when placed in contact with the aluminum storm sewer material must have a pH range of 4 to 9 and a minimum resistivity of greater than 500 ohm-cm. Samples of 4 local granular materials available in sufficient volume for this project were submitted to the Kaiser Center for Technology and Dr. Robert K. Morse for analysis of not only the pH and minimum resistivity, but also gradation, clay content, and ability to be compacted. Results of those tests indicated that all four materials submitted were acceptable. However, the river sand available at a location in Peru, Illinois, was determined to be the most desirable and was ultimately used primarily due to the availability and cost. Figure I-8, sample No. 8 represents a post construction analysis of the select granular material utilized. Native materials were specified to be placed in contact with the aluminum pipe only at selected locations which were referenced for future evaluation. One inch by six inch standard corrugation annular aluminum pipe was specified to be utilized for 42 inch through 72 inch diameter pipe and one half inch by two inch helically corrugated aluminum pipe was specified for diameters ranging from 12 inch through 36 inch. Thickness or gauge of aluminum material was selected from the Standard Specifications for Corrugated Aluminum Alloy Culvert Pipe published by the American Association of State Highway Officials Designated M196-65 and was checked against the Federal Specifications for Pipe, Corrugated (Aluminum Alloy) published by the General Services Administration designated WW-P-402a. Alignment of the 72 inch diameter outfall sewer intersected two railroad lines and required special design considerations for those crossings. A steel plate tunnel liner was specified to be constructed under the Rock Island Railroad Tracks because it was necessary to maintain uninterrupted service. The steel liner was constructed and the invert was paved with asphalt and all surfaces were coated with bitumastic material prior to inserting the 72 inch diameter aluminum pipe through the steel plate liner. A reinforced concrete "sleeve" was specified for construction under the Chicago, Burlington & Quincy Railroad because open cutting was permitted. A substantial portion of the storm sewer system was constructed in limestone rock which exists at a rather shallow depth in the Southern part of the City. Bitumastic material was specified to be applied to the exterior surfaces of all aluminum pipe to be constructed in direct contact with either concrete or any other metals. Aluminum fittings such as coupling bands, bends, stubs, tapping saddles, and reducers were also specified and bids were taken on these items separate from the aluminum pipe and aluminum structural plate arch materials as part of the same contract. Methods of construction specified were standard methods of construction utilized for this type of work where materials other than aluminum pipe are incorporated into the project.

SECTION H

SPECIFICATIONS AND CONSTRUCTION OF DEMONSTRATION STORM SEWER AND APPURTENANCES

PROSECUTION OF MATERIAL ACQUISITION AND INSTALLATION

The contract for the supply of material was executed on June 16, 1971, between the City of LaSalle and Kaiser Aluminum and Chemical Sales, Inc. The contract for installation and incidental construction was executed on June 14, 1971, between the City of LaSalle and Central Illinois Contracting Corporation of Peru, Illinois. Construction of the demonstration aluminum storm sewer began July 10, 1971, and was substantially completed on June 30, 1973.

CONSTRUCTION PLANS

The detailed plans and specifications were utilized by the Contractor and the project engineers to construct the demonstration aluminum storm sewer. The construction plans consisted of 88 sheets of plan and profile and detail sheets.

ALUMINUM PIPE SUPPLY, STORAGE AND DISTRIBUTION

Both standard and helical corrugated aluminum pipe was supplied in 20-foot long sections and was shipped by railroad car in a "nested" arrangement. The material was unloaded from the railroad cars and transported to a central storage location located at the Southeast area of the City of LaSalle. Material was transported by the Contractor from the central storage location when needed to the job site. The structural plate material was delivered by truck in bundled sections and transported to the central storage area until required on the job site. The structural plate arch was bolted to aluminum angles anchored to a smooth concrete invert. The entire structural plate arch was erected from the prefabricated sheets in the field.

MATERIAL SPECIFICATIONS - STANDARD AND HELICAL CORRUGATION PIPE

The specifications for the aluminum material utilized for this project were as follows:

Description

This work shall consist of furnishing and delivering to the City of LaSalle, Illinois, aluminum helical or riveted round aluminum corrugated pipe, accessories and fittings, in accordance with the following requirements.

Materials

General --

Corrugated aluminum alloy pipe shall be fabricated from corrugated clad aluminum alloy sheets or coils conforming to the chemical composition shown in Table H-1. The cladding thickness on each side shall be five percent of the total composite thickness. The mechanical properties given in ASTM Specification B209 for alloy Alclad 3004 with Temper H34 as in Table H-2 shall be met.

Rivets shall conform to the chemical composition shown in Table I of ASTM Specification B316, for alloy 6053 heat treated to the T4 temper with the following minimum mechanical properties:

Tensile Strength ---- 25,000 psi
Yield Strength ---- 14,000 psi
Shear Strength ---- 15,000 psi
Elongation ---- 16 pct.

Coupling bands shall be of the same alloy as the pipe. Angles or lugs shall conform to the chemical composition, shown in Table H-1, and the mechanical properties of ASTM Specification B221, alloy 6063 with Temper T-6 as given in Table H-10.

Sampling (When Verification of Chemical Analysis Required) --

Chemical analysis of sheets before fabrication shall be made from drillings or chips from samples of metal cut from different sheets in a lot. When referred analysis is required, samples for chemical analysis shall be taken from the core alloy after removal of the cladding by etching or milling. A sample shall be taken from each of three different sheets for lots weighing five tons or less, from four sheets for lots weighing more than five and less than ten tons, and from five sheets for lots weighing ten tons or more. The drilling or chips from these samples shall be thoroughly mixed for analysis.

Sheet Manufacturer's Guarantee --

The manufacturer of the sheets shall submit with the certified analysis a guarantee providing that all metal furnished shall conform to the specification requirements, shall bear a suitable identification brand or mark, and shall be replaced without cost to the purchaser when not in conformity with the specified analysis, thickness, or cladding; and the guarantee shall be so worked as to remain in effect so long as the manufacturer continues to furnish material.

Sheet Manufacturer's Certified Analysis --

The manufacturer of each brand shall file with the Engineer a certificate setting forth the name or grade of metal to be furnished and a statement that the material conforms to the specified chemical composition. The certificate shall be sworn to for the manufacturer by a person having legal authority to bind the company.

Identification --

No pipe will be accepted unless the metal is identified by a stamp on each section showing:

(1) Name of sheet manufacturer
(2) Name of brand and kind of base metal
(3) Manufacturer's standard thickness (See Table H-5)
(4) Manufacturer's date of processing by a six (6) digit number indicating in order the year, month and days of the month.

The identification brands shall be placed on the sheets by the manufacturers of the sheets in such a way that when rolled into pipe such identification shall appear on the outside of each section of pipe. Pipe having any sections not so stamped shall be promptly rejected. The kind of base metal shall be designated independently of the brand or trade mark so as to clearly identify the base metal furnished. The identification of the kind of "base metal" shall be accomplished by placing on the sheets alloy number and temper.

No metal will be accepted under these specifications and no bids will be considered for the materials above described until after the sheet manufacturer's certified analysis and manufacturer's guarantee have been passed upon by the Engineer and accepted. Misbranding or other misrepresentation, and non-uniformity of product, will each be considered a sufficient reason to discontinue the acceptance of any brand under these specifications and notice sent to the sheet manufacturer of the discontinuance of acceptance of any brand will be considered to be notice to all companies which handle that particular brand. The kind of base metal which will be furnished shall be designated by the bidder. One brand, and one brand only, shall be approved for each kind of base metal furnished by each of the actual manufacturers of the sheets.

Inspection and Rejection --

If the Engineer so elects, he may have the material inspected and sampled in the rolling mill or in the shop where fabricated. He may require from the mill the chemical analysis of any lot. The inspection, either in the mill or in the shop, shall be under the direction of the Engineer. The Engineer or his representative shall have free access to the mill or shop for inspection, and every facility shall be extended to him for this purpose. Any material or pipe which has been previously rejected at the mill or shop and included in a later lot will be considered sufficient cause for the rejection of the entire lot.

The field inspection shall be made by the Engineer, who shall be furnished by the seller with an itemized statement of the sizes and lengths of pipe in each shipment. This inspection shall include an examination of the pipe for deficiency in nominal specified diameter, net length of furnished pipe, and any evidence of poor workmanship as outlined above. The inspection may include the taking of samples for chemical analysis. The pipe making up the shipment shall fully meet the requirements of these specifications; and if 25 percent of the pipe in any shipment fails to meet these requirements, the entire shipment may be rejected.

Testing --

Unless otherwise provided, chemical analysis, when required, shall be in accordance with Standard Method E-34 of the American Society for Testing and Materials except that suitable spectographic analysis likewise may be employed.

When the thickness of the cladding of finished sheet is to be determined, a minimum of three transverse samples, representing the width of the sheet and approximately 3/4 inch in length, shall be mounted to expose a plane perpendicular to the plane of the sheet, and polished for microscopic examination. After etching with a mixed acid etch to differentiate between core and cladding, each specimen shall be examined at a magnification of 100 diameters and the maximum and minimum cladding thickness shall be measured in each of five fields approximately 1/10 inch apart along both sides of the exposed edge of each specimen. The average of the ten measurements of thickness of each side of the exposed edge of each mounted specimen will be used to determine the cladding thickness of the material.

Fabrication

Shape --

Pipe furnished under this specification shall be full circle or full circle 5% elongated pipe except that pipe with 6 x 1 corrugations shall be full circle only.

Type --

Pipe furnished under this specification shall be helically corrugated lock seam or annular riveted with 6 x 1 corrugations.

(1) Riveted Annular Corrugated Pipe, 6 x 1 Corrugation Shape -- Pipe furnished shall be of the full circle type with lap joint construction.

Dimensions and Weights -- The widths of laps, nominal thicknesses and computed weights per linear foot of furnished pipe shall be as specified in Table H-3. The dimensions given for diameter of pipe are nominal inside diameters.

Rivets and Riveting -- Rivets shall be for following diameters as specified:

Diameter, inch	Diameter, inch
30" thru 42"	3/8"
42" and up	1/2"

All rivets shall be driven cold in such a manner that the plates shall be drawn tightly together throughout the entire lap. The center of a rivet shall not be closer than 1½ times the diameter of the rivet from the edge of the metal. Longitudinal seams shall be riveted with two rivets in each crest and valley of each corrugation. All rivets shall have neat, workmanlike heads of a form acceptable to the Engineer, shall be driven without bending, and shall completely fill the hole. Circumferential, shop-riveted seams shall have a maximum rivet spacing of 6 inches.

Corrugations -- Corrugations shall be not less than 5-7/8" nor more than 6-1/8" center to center of either crest or valley. The corrugations shall have a depth of not less than one inch.

Coupling Bands -- Field joints shall be made with bands not less than 18 inches wide for pipe diameters of 30 inches to 60 inches, inclusive; and not less than 24 inches wide for pipe culverts with diameters greater than 60 inches. The thickness of such bands shall conform to Table H-3. They shall be connected at the ends by aluminum alloy angles having minimum dimensions of 2 inches by 2 inches by 3/16 inch, or by aluminum alloy lugs. The 18-inch band shall have not less than three and the 24-inch band shall have not less than four galvanized steel 1/2-inch bolts. Other equally effective methods of connecting the coupling bands may be used if approved by the Engineer. Those heat-shrinkable bands supplied in accordance with the requirements of the Special Provisions for all sizes of 1" x 6" pipe shall be a heat-shrinkable type band constructed of high density polyolefin with a minimum heat shrinking capacity of not less than 25%, as manufactured by the Ray Chem Corporation, 300 Constitution Drive, Menlo Park, California. For pipe diameters of 12-inch to 30-inch inclusive, the band shall be a minimum of 8 inches wide prior to shrinking. For pipe diameters of 36-inch to 72-inch inclusive, the band shall be a minimum of 12 inches wide prior to shrinking.

(2) Helically Corrugated Pipe --

Shape -- Pipe furnished may be full circle or full circle 5% elongated with continuous helical lock seam construction. The minimum radius of curvature of any part of the pipe section shall be three inches.

Dimensions and Weights -- Helically corrugated aluminum alloy pipe shall have nominal thicknesses and nominal weights per lineal foot as shown in Table H-4. The average weight per lineal foot of finished pipe shall not underrun the weight given in Table H-4 by more than five percent.

Helical Lock Seam -- The lock seam shall be parallel to the corrugation, extend continuously from end to end of the pipe and shall be fabricated so as not to affect the shape or nominal diameter of the pipe. Lock seam pipe shall be mechanically staked at approximately one inch (1") centers by a method which will supply sufficient pressure to indent the outside layer of metal in the lock seam into the adjacent layer and thereby provide insurance against seam slippage.

Corrugations -- Helically corrugated pipe having a diameter of 10 inches or less shall have corrugations not less than 1-3/8 inches nor more than 1-7/8 inches center to center, measured at right angles to the direction of the corrugations and shall have a depth of not less than 1/4 inch.

Helically corrugated pipe having a diameter of 12 inches or greater shall have corrugations not less than 1-7/8 inches nor more than 2-3/4 inches center to center, measured at right angles to the direction of the corrugations. Pipe having diameters of not less than 12 inches nor more than 21 inches shall have corrugation depth of not less than 7/16 inch. Pipe having diameters greater than 21 inches shall have corrugation depth of not less than 1/2 inch.

The angle between the direction of the corrugations and the longitudinal axis of the pipe shall not be less than 45 degrees.

Coupling Bands -- Field joints in helically corrugated aluminum alloy pipe shall be made with aluminum alloy band couplers of the same base alloy as that used in the pipe. Band couplers shall have corrugations that mesh with the corrugations of the pipe. Bands shall be not less than 7 inches wide for pipe diameters of 6 inches to 30 inches, inclusive; not less than 12 inches wide for pipe with diameters of 36 inches to 60 inches, inclusive; not less than 24 inches wide for pipe with diameters greater than 60 inches. The thickness of such bands shall conform to Table H-4. All bands shall be constructed so as to lap circumferentially. One piece band couplers only may be used. Pipe diameters of not less than 12 inches with the

7-inch band shall be fastened with not less than two galvanized steel bolts of not less than 1/2 inch diameter. The 12-inch band shall be fastened with not less than three galvanized steel bolts of not less than 1/2 inch diameter. The 24-inch band shall be fastened with not less than five galvanized steel bolts of not less than 1/2 inch diameter. For pipe diameters 12" thru 30", a one-piece "Slip Seam" band may be used. Minimum widths specified above apply. The slip seam band shall be fabricated from pipe about 1/2" oversize with the lock seam sufficiently loose to slip. A mechanical connector containing a single 1/2" steel bolt shall be attached to the sliding seam in such a manner that turning the bolt in one direction opens the band while turning in the opposite direction closes the band. "Dimple" type bands will not be allowed. Heat shrinkable bands supplied in accordance with the requirements of the Special Provisions for all sizes of pipe shall be a heat-shrinkable type band constructed of high density polyolefin with a minimum heat shrinking capacity of not less than 25%, as manufactured by the Ray Chem Corporation, 300 Constitution Drive, Menlo Park, California. For pipe diameters of 12-inch to 30-inch inclusive, the band shall be a minimum of eight inches wide prior to shrinking. For pipe diameters of 36-inch to 72-inch inclusive, the band shall be a minimum of 12 inches wide prior to shrinking. Other equally effective methods for connecting the sections may be used if approved by the Engineer.

MATERIAL SPECIFICATIONS - ALUMINUM PLATE ARCH

The specifications for aluminum corrugated structural plate arch were as follows:

Materials

General --

All plates shall be fabricated from aluminum alloy 5052-H141 The chemical composition of the plates shall be ASTM designation B209 alloy 5052 and shall conform to chemical compositions as shown on Table H-7. All aluminum bolts, nuts and structural shapes where specified on drawings shall be ASTM designation B221 alloy 6061 and shall conform to chemical compositions as shown on Table H-7. All bolts shall conform to the physical requirements of Table H-8.

Plate Thickness Determination and Tolerance --

The nominal thickness and thickness tolerance of the plates shall be given in Table H-9. The theoretical weight of flat sheet alloy 5052-H141 is given in Table H-9.

Sampling (When Verification of Chemical Analysis is Required) --

For testing for chemical analysis a sample shall be provided for each 100 plates of a shipment or fraction thereof.

The sample may be obtained from a piece approximately 3" square cut from a corner of a plate. The coupon shall be of the same nominal thickness and base metal as the plate to which it is attached.

Sheet Manufacturer's Certified Analysis --

The manufacturer of the base metal shall file with the Engineer a certificate setting forth the name or brand of metal to be furnished, a typical analysis, and a statement that the material conforms to the specified chemical composition limits. The certificate shall be sworn to for the manufacturer by a person having legal authority to bind the company.

Sheet Manufacturer's Guarantee --

The manufacturer of the sheets shall submit with the certified analysis a guarantee providing that all metal furnished shall conform to the specification requirements, shall bear a suitable identification brand or mark and shall be replaced without cost to the purchaser when not in conformity with the specified analysis or thickness; the cost to be limited to the replacement of structural plate material only. The guarantee shall be so worded as to remain in effect so long as the manufacturer continues to furnish material.

Identification --

No plates will be accepted unless the metal is identified by a stamp on each plate showing:

Name of base metal manufacturer.
Name of brand and kind of base metal or alloy designation.
Manufacturer's standard thickness.
Manufacturer's date of processing by a six (6) digit number indicating in order the year, month and day of month.

The identification stamps shall be so placed that when the pipe or arch is erected the identification will appear on the inside of the structure.

Field Inspection and Acceptance of Plates --

The field inspection shall be made by the Engineer, and he shall be furnished by the manufacturer an itemized statement of the number and length of the plates in each shipment. Each plate included in the shipment shall meet fully the requirements of these specifications. If 25% of the plates in any shipment fail to meet the requirements, the entire shipment may be rejected.

Methods of Testing --

Unless otherwise provided, chemical analysis, when required, shall be in accordance with Standard Method E 34 of the American

Society for Testing and Materials, except that suitable spectrographic analysis likewise may be employed.

Workmanship --
It is the essence of these specifications that in addition to compliance with the details of construction, the completed structure shall show careful finished workmanship in all particulars. The requirement applies not only to the individual plates but to the shipment on any contract as a whole.

Fabrication

Shape --
Material furnished under this specification shall be pure arch, conforming to the general shapes shown on the plan detail.

Type --
Pipe furnished under this specification shall consist of curved corrugated structural units. When assembled, the corrugations shall run at right angles to the longitudinal axis of the structure. Curved structural plate units shall be bolted together to form structures as specified herein.

Shape -- Structural plate arches shall consist of a curved crown segment of uniform radius as shown on the plan detail and shall consist of the span, rise, and cross-sectional area shown on the plan detail.

Dimensions and Weights -- Individual plates may be supplied in widths from approximately 80 inches to 140 inches and shall have a net length of not less than 45 inches or greater than 72 inches. Individual plates shall not weigh more than 250 pounds. Sizes and dimensions of completed structures shall be as specified or shown on the plans.

Forming and Punching Plates -- Plates shall be formed to provide lap joints. The bolt holes shall be so punched that all plates having like dimensions, curvature, and the same number of bolts per foot of seam shall be interchangeable. Each plate shall be curved to the proper radius so that the cross-sectional dimensions of the finished structure will be as indicated on the drawings or as specified.

Unless otherwise specified, bolt holes along those edges of the plates that will form longitudinal seams in the finished structure shall be in two rows, 1-3/4 inches apart, in the valley and in the crest of the corrugations. Bolt holes along those edges of the plates that will form circumferential seams in the finished structure shall provide for a bolt spacing of not more than 12 inches. The minimum distance from center of hole to edge of the plate shall not be less than 1-3/4 times the diameter of the bolt. The diameter of the bolt holes in the longitudinal seams shall not exceed the diameter of the bolt by more than 1/8 inch, with the following exception: for purposes of ease in assembling plates, the two corner holes plus the two adjacent holes along the longitudinal seam shall be increased not to exceed the bolt diameter by more than 1/4 inch.

Plates for forming skewed or beveled ends shall be cut so as to give the angle or skew or slope specified. Plates shall be saw cut, not burned, and present a workmanlike finish. Legible identification symbols shall be placed on each part plate to designate its proper position in the finished structure.

Corrugations -- Corrugations shall have a pitch of not less than 8-5/8 inches or greater than 9-3/8 inches and a depth of not less than 2-3/8 inches or greater than 2-5/8 inches. Each corrugation shall have a minimum curved radius of 2 inches.

Plate Joining -- Field joints shall be made with 3/4 inch diameter aluminum or steel bolts as specified. Bolts shall be American Standard Course Thread, Class 2, Free Fit with hexagonal heads and nuts. Bolt heads and nuts shall be shaped to provide improved bearing.

All bolts shall be torqued to a minimum of 100 foot pounds. The maximum torque to be applied to aluminum bolts shall be 150 foot pounds and to steel bolts 250 foot pounds.

MATERIAL SPECIFICATIONS - GRAVEL CRADLE

Gravel cradle, conforming to the details indicated on the plans, shall be constructed prior to the placement of all sewers, except when omission is ordered by the Engineer. Materials for gravel cradle shall be dredged or bank run sand or gravel or crushed stone and well graded within the limits stated below. The type of gravel cradle to be used in specific locations will be designated by the Engineer. Where the natural foundation soil, on which the pipe is to be bedded, consists of granular material suitable in its natural state for shaping and embedding a sewer, no gravel cradle will be required. For reasonably good, non-granular foundation conditions, Type A gravel cradle will be designated. Where, in the opinion of the Engineer, the foundation conditions are not suitable for the use of Type A gravel cradle, then Type B gravel cradle may be used, the actual selection to be made by the Engineer.

TABLE H-1. CHEMICAL COMPOSITION LIMITS OF ALUMINUM STOCK MATERIALS

Aluminum Alloy	Purpose	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others	
										Each	Total
Alclad 3004 H34	Sheet or Coil Core.........	.3	.7	.25	1.0-1.5	0.8-1.3	...	.25	..	.05	.15
	Sheet or Coil Cladding.....	Si + Fe =.7	...	.10	.10	.10	...	0.8-1.3	..	.05	.15
6053-T4	Rivets........	*	.35	.10	...	1.1-1.4	.15-.35	.10		.05	.15
6063-T6	Angles or lug.	.2-.6	.35	.10	.10	.45-.9	.10	.10		.05	.15

* 45 to 65 percent of magnesium content
** Units in percent maximum unless shown as range

TABLE H-2. MECHANICAL PROPERTIES OF ALLOY ALCLAD 3004-H34

Thickness, In.	Tensile Strength, psi		Yield Strength (0.2% offset) psi.	Elongation in 2 in. %
	Minimum	Maximum	Minimum	Minimum
0.051 to 0.113	31,000	37,000	24,000*	4
0.114 to 0.249	31,000	37,000	24,000*	5

*Yield strength to be determined only when specified in the contract or purchase order

TABLE H-3. DIMENSION & WEIGHTS OF ANNULAR RIVETED 6 X 1 CORRUGATION ALUMINUM ALLOY PIPE

Nominal Diameter	Nominal Length of Sheet	Minimum Length of Lap	Nominal Thickness of Sheet*	Computed Weight Per Linear Ft. of Finished Pipe for the Various Nominal Thickness Exclusive of the End Finish					Connecting Bands Nominal Thickness
Inches	Inches	Inches	Inches	.060 in Pounds	.075 in Pounds	.105 in Pounds	.135 in Pounds	.164 in Pounds	Inches
30	101	3	.060 .075 .105	8.30	10.30	14.27			.060
36	119-1/2	3	.060 .075 .105	9.80	12.17	16.85			.060
42	138-1/2	3	.060 .075 .105	11.35	14.09	19.51			.060
48	157-1/2	3	.060 .075 .105	12.17	16.29	22.49			.060
54	176-1/2	3	.060 .075 .105	14.74	18.24	25.18			.060
60	195	3	.075 .105 .135		20.12	27.79	35.59		.060
66	213-1/2	3	.075 .105 .135		22.02	30.41	38.95		.060
72	232-1/2	3	.075 .105 .135		23.96	33.10	42.40		.060
78	251-1/2	3	.075 .105 .135		25.90	35.78	45.83		.060
84	270-1/2	3	.105 .135 .164			38.46	49.27	59.65	.075
90	290	3	.105 .135 .164			41.15	52.72	63.82	.075
96	308-1/2	3	.105 .135 .164			43.85	56.17	68.01	.075

* Different nominal thicknesses are shown for use in design for various height of fill over the top of the pipe. The thickness should be based on the design requirements for each installation and should be shown on the plans or in the proposal.

** Two sheet of similar length may be used in fabricating pipe 42 inches and larger in diameter by providing for additional standard lap.

TABLE H-4. DIMENSIONS AND WEIGHTS OF HELICALLY CORRUGATED ALUMINUM ALLOY PIPE

Nominal Diameter	Nominal Thickness of Sheet*	Computed Weight Per Linear Ft. of Finished Pipe for the Various Nominal Thickness Exclusive of the End Finish						Connecting Bands Nominal Thickness
Inches	Inches	.048 in Pounds	.060 in Pounds	.075 in Pounds	.105 in Pounds	.135 in Pounds	.164 in Pounds	Inches
6	.048 .060	1.30	1.60					.060
8	.048 .060	1.72	2.14					.060
10	.048 .060	2.14	2.66					.060
12	.060 .075		3.17	3.98				.060
15	.060 .075 .105		3.93	4.93	6.90			.060
18	.060 .075 .105		4.69	5.89	8.24			.060
21	.060 .075 .105		5.45	6.84	9.56			.060
24	.060 .075 .105 .135		6.25	7.80	10.90			.060
30	.075 .105 .135 .164			10.24	14.35	18.48		.060
36	.075 .105 .135 .164			12.25	17.17	22.00		.075
42	.105 .135 .164				19.99	25.61		.075
48	.105 .135 .164				22.81	29.22		.075
54	.105 .135 .164				26.65	32.85		.075
60	.135 .164					36.42		.105

* Different nominal thicknesses are shown for use in design for various height of fill over the top of the pipe. The thickness should be based on the design requirements for each installation and should be shown on the plans or in the proposal.

** The above computed weights are for a corrugation configuration of one-half by two inches. If material supplied has a corrugation configuration of one-half by two and two-thirds inches, a five percent (5%) reduction in the above computed weights will be acceptable.

TABLE H-5. SHEET THICKNESS

Nominal Thickness in Inches	Equivalent U.S. Gauge Number
.060	16
.075	14
.105	12
.135	10
.164	8

TABLE H-6. PERMISSIBLE VARIATIONS FROM ORDERED WEIGHT FOR ALL OF ONE NOMINAL THICKNESS AND SIZE

Alum Sheet (nominal thickness)	Weight of Aluminum Sheets**	Permissible Variations From Special Weight, * Percentage Over or Under		
Inches	Lb.Sq.Ft.	20 Tons & Over	Under 20 Tons to 3 Tons Inc.	Under 3 Tons
.164	2.47	3.5	5	7.5
.135	2.02	3.5	5	7.5
.105	1.57	3.5	5	7.5
.075	1.11	3.5	5	7.5
.060	0.88	3.5	5	7.5

* The tonnage ordered for shipment to one place at one time determines the permissible variation for that tonnage, though any partial shipment may have the greater permissible variation of its tonnage classification.

** Weights shown are for flat sheets. Nominal weights for flattened sheets may be reduced 7 percent.

TABLE H-7. CHEMICAL COMPOSITION LIMITS OF ALUMINUM STRUCTURAL PLATE MATERIALS

Chemical Content	Plate Alloy 5052-H141	Bolts & Nuts Alloy 6061-T6
Si	(0.45 Si + Fe)	.40 - .8
Fe		.7
Cu	.10	.15 - .40
Mn	.10	.15
Mg	2.2 - 2.8	.8 - 1.2
Cr	.15 - .35	.15 - .35
Zn	.10	.25
Ti		.15
Each	.05	.05
Others		
Total	.15	.15

* All steel bolts when specified on drawings shall be either ASTM designation A-325 or A-307 and shall be hot, double-dipped galvanized.

** Minimum mechanical properites of all materials shall be shown on Table H-8.

*** Units in percent maximum unless shown as range

TABLE H-8. PHYSICAL PROPERTIES OF MATERIALS

Aluminum	Thickness Range (Inches)	Min. Tensile Strength (Psi)	Min. Elongation in % Per 2 in.
5052-H141	0.090 - 0.175	35,500	6
" "	0.175 thru .250	34,000	8
6061-T6		42,000	10

* Aluminized steel bolts or other equally effective methods of connecting plates may be used if approved by the Engineer.

TABLE H-9. NOMINAL THICKNESSES, THICKNESS TOLERANCES AND THEORETICAL WEIGHT FOR FLAT SHEET ALUMINUM ALLOY 5052-H141

Nom. Thickness Inches	Theoretical Wt. Of Flat Sheet #/Sq. Ft.	Permissible Variation in Inches
0.100	1.39	.014
0.125	1.74	.014
0.150	2.09	.024
0.175	2.44	.030
0.200	2.79	.030
0.225	3.13	.032
0.250	3.48	.036

TABLE H-10. MECHANICAL PROPERTIES OF ALLOY 6063-T6

Thickness,* Inches	Area Sq. In.	Tensile Strength Min., psi	Yield Strength 0.2% Offset Min., psi	Elongation in 2" or 4 x Dia. Min.%**
Up thru 0.124	All	30,000	25,000	8
0.125 to 1.000	All	30,000	25,000	10

* The thickness of cross-section from which the tension test specimen is taken determines the applicable mechanical properties. For material 1-1/2 in. or less in thickness when not tested in full section, the tension test specimen is taken from the center of the section. Specimens are taken parallel to the direction of extrusion.

** For material of such dimensions that a standard test specimen cannot be taken, or for material thinner than 0.062 in., the test for elongation is not required.

SIEVE SIZE FOR TYPE A GRAVEL CRADLE

SIEVE SIZE	% PASSING
1½"	100%
1"	90 - 100%
1/2"	60 - 100%
#4	40 - 80%
#8	25 - 60%
#16	20 - 45%
#200	Max. 15%

SIEVE SIZE FOR TYPE B GRAVEL CRADLE

SIEVE SIZE	% PASSING
1½"	100%
1"	60 - 95%
1/2"	10 - 30%
#4	0 - 5%

Material used shall have a minimum pH of 4.0 and a maximum pH of 9.0 and a minimum resistivity of 1000 ohm-cm or greater.

The gravel cradle shall be placed so that at least the lower 1/2 of the pipe will be uniformly supported for its entire length. Special care shall be taken to compact the material under the haunches of the pipe. Where a trench is required, the width at the top of the pipe shall be sufficient to permit thorough tamping of the foundation and backfill material.

If the foundation has been made deeper than necessary, the foundation shall be brought to the proper grade by the additional material specified for gravel cradle.

MATERIAL SPECIFICATIONS - SELECTED GRANULAR BACKFILL

Unless otherwise ordered by the Engineer, material conforming to this specification for selected granular backfill shall be used in locations indicated on the plan details where the aluminum storm sewer is constructed under permanent type pavement, driveways or sidewalks. Selected granular backfill shall be compacted by jetting before the permanent type surface is reconstructed, unless such compaction is waived by the Engineer. Material for selected granular backfill shall consist of dredged or bank run sand or gravel or crushed stone, well graded within the following limits:

SIEVE SIZE	% PASSING
1½"	100%
1"	90 - 100%
1/2"	60 - 100%
#4	40 - 80%
#8	25 - 60%
#16	20 - 45%
#20	Max. 15%

Material used shall have a minimum pH of 4.0 and a maximum pH of 9.0 and a minimum resistivity of 1000 ohm-cm or greater.

The contractor shall notify the Engineer of the source of material he proposes to use for selected granular backfill and arrange for samples to be taken prior to the time such material is ordered to the site. Material graded to sizes other than those specified may be substituted for that specified, providing the gradation and samples are first submitted and approved for the intended purpose by the Engineer.

DETAILED DESCRIPTION OF CONSTRUCTION WORK

The aluminum pipe was delivered from the central storage area as needed to the job site. The first section of aluminum storm sewer to be constructed was on Second Street from Wright Street eastward. This section involved 21" and 30" helically corrugated aluminum pipe. The aluminum storm sewer pipe was installed throughout the entire project as follows.

The existing pavement was saw-cut in order to remove the necessary width of pavement along the route of the proposed trench. After the pavement was removed, the trench was excavated to a depth of 3 inches lower than the proposed flow line grade of the aluminum storm sewer. A 3 inch thick gravel cradle was constructed prior to placing of the aluminum pipe. The aluminum pipe was then lowered into the trench by two men utilizing either ropes or simply passing the 20-foot lengths of pipe to workmen in the trench. The aluminum pipe was then placed to proper line and grade and select granular backfill was placed and compacted to an elevation of one foot above the top of the aluminum pipe. Samples from various stockpiled gravel cradle and select granular backfill material were analyzed prior to being approved for use. These samples were analyzed for pH and minimum resistivity in order to determine in advance whether or not this material would be compatible with the aluminum pipe from the standpoint of corrosive effects. Samples from four different sources were analyzed. These samples were determined to have a pH range of 7.2 to 8.9 and a minimum resistivity of 7,142 ohm-cm to 58,333 ohm-cm. The material selected was a sand material derived from dredging operations in the Illinois River. This particular material was determined to have a pH of 7.6 and a minimum resistivity of 7,142 ohm-cm. In accordance with report MSPR 69-57 "Correlation of Culvert Field Performance with Soil and Water Characteristics" which stated that aluminum pipe can be safely used in soils having a pH range of 4-9 and a minimum resistivity of greater than 500 ohm-cm, this material was determined to be compatible with aluminum pipe from the standpoint of corrosive effects. Native backfill was placed above the select granular backfill at locations where no permanent surface such as roadway or sidewalk was to be constructed. Select granular backfill was utilized for the entire depth of the trench at locations where hard surfaced areas such as roadway or sidewalks were to be constructed over the trench. Native backfill materials of various types were placed in direct contact with the aluminum pipe at predetermined locations for the purpose of analyzing the effects of this material upon the aluminum pipe during the annual inspection tours. Care was taken throughout the length of construction to avoid any direct contact between the aluminum pipe and other metals such as steel, cast iron and copper underground conduit, the purpose of which was to eliminate a potential galvanic action problem between two dissimilar metals. However, it was discovered during the annual inspection tours that there had apparently been an inadvertent coupling between a steel tunnel liner under the Chicago, Rock Island and Pacific Railroad tracks through which a 66" diameter aluminum pipe had been placed. The steel tunnel liner was constructed to carry the railroad traffic load and was asphalt coated and bituminous concrete paved prior to placing the bituminous coated aluminum pipe through the steel tunnel liner. The electrical connection between the steel and the aluminum apparently occurred despite the precautions which were taken. Areas of corrosive attack were observed on the aluminum pipe in the area of the steel tunnel liner during the annual inspection tours. The length of aluminum pipe affected by this condition is approximately 50 lineal feet of 66" aluminum pipe and magnesium sacrificial anodes have been installed to provide cathodic protection for this section of pipe. The aluminum storm sewer was constructed at various depths, in various diameters from 12" through 72" at various locations and excavating conditions throughout a rather large geographic area within the City of LaSalle. The majority of the aluminum pipe was easily handled by either workmen or light equipment to lower the pipe into the trench. The vast majority of aluminum pipe installed was placed in 20-foot lengths in accordance with the typical trench details shown in Figures H-2 through H-4. The aluminum circular pipe was connected by coupling bands of the same material as the aluminum pipe. The bands were placed around the ends of the jointed pipe and bolted to provide a permanent tight joint. Construction procedures for the installation of aluminum pipe were essentially the same as those for any other pipe material with the significant exception of the aluminum pipe being much easier to handle and lower into the trench and because of the 20-foot length of the pipe, a significantly lesser number of joints were required which allowed for a greater production rate in areas where existing underground utilities were not the controlling factor in the length of trench which could be opened to accommodate the pipe. The structural plate arch was bolted to aluminum angles embedded in a concrete base in accordance with the typical trench detail shown in Figure H-4. Select granular backfill was utilized around the entire perimeter of the structural plate arch material to an elevation of at least 1 foot above the top of the plate arch material. Similar precautions taken for circular pipe were taken during the installation of the aluminum plate arch in order to avoid an inadvertent electrical connection between two dissimilar metals. All sections of aluminum corrugated pipe and aluminum structural plate arch pipe which were constructed in direct contact with concrete were coated with a bitumastic material prior to being exposed directly to the concrete. This was done as an "insurance" measure since there has been no previous indication of any detrimental action between concrete and aluminum. The general construction procedures such as excavation, utilization of gravel cradle, and select granular backfill are similar to those specified for projects utilizing other materials such as corrugated steel pipe, and reinforced concrete pipe. However, it was recognized that a greater degree of care would be required during the placing and backfilling operations of metal pipe versus concrete pipe because of the lesser resistance to "egg shelling" possessed by the thinner walled metal pipe as opposed to the thicker walled reinforced concrete pipe.

A complete 35 mm slide pictorial record was kept of all construction phases of the project and the highlights of that record is presented in Figures H-5 through H-26.

Construction of Aluminum Outfall Sewer on Steep Slope

It was necessary to provide an outfall storm sewer from First Street to Canal Street - a length of approximately 200 feet and an elevation difference of approximately 36 feet. The 66-inch diameter standard corrugation aluminum pipe was utilized in conjunction with specially fabricated bends to effect the necessary vertical and horizontal alignment to connect the upper elevation sewer to the lower elevation outfall. The coupling bands for this section of pipe were bolted together and also bolted directly to the entire perimeter of the ends of the pipe being connected. Also the lower bend was completely encased in concrete to prevent any horizontal or vertical movement caused by hydraulic forces in the steep-slope pipe or the weight of the pipe and backfill above the lower bend.

Construction of Special Railroad Crossings

It was necessary to provide a steel tunnel liner under the Chicago, Rock Island and Pacific Railroad and a concrete "sleeve" under the Chicago, Burlington, and Quincy Railroad. Permission was granted to open cut the Chicago, Burlington, and Quincy Railroad and therefore, the concrete sleeve was placed in the open trench and backfilled. The concrete sleeve was utilized in order to carry the extremely heavy loads produced by trains. Permission could not be obtained to open cut the Chicago, Rock Island and Pacific Railroad and it was, therefore, necessary to tunnel under these tracks. Steel ribbed liner plate was selected to be utilized in this area because of its relative ease of installation which involved being bolted together in sections as the tunneling operation progressed. The 72-inch aluminum standard corrugation pipe inserted through the concrete pipe liner and the steel tunnel liner was coated with bitumastic material and the invert of the steel tunnel was paved with bituminous concrete.

Construction of Appurtenant Structures

All manholes were either precast concrete or cast-in-place concrete structures with the exception of the aluminum demonstration manholes constructed at selected locations for the purpose of monitoring over the 10-year post construction evaluation period. It was determined during the design phase of the project that conventional concrete manholes and cast-in-place reinforced concrete structures would be more practical due to the relatively high cost of fabricating special aluminum structures to be utilized for these purposes.

Construction of Special Joints, Bends, and Connections

Deflection of larger diameter pipes were accomplished by incorporating pre-fabricated bends into the system at locations where manholes were not required. Connections of smaller diameter pipes to larger diameter pipes and plate arch was accomplished by utilizing pre-fabricated tapping saddles which were installed by cutting a hole in the pipe to be tapped and bolting the tapping saddle to the pipe. The final connection of the smaller diameter pipe was made with either a standard coupling band or a heat shrinkable coupling band.

DISCUSSION OF RESULTS

It was extremely difficult to keep and maintain meaningful cost records during construction because the method of construction utilized for the installation of aluminum pipe is essentially identical to the method of construction utilized for the installation of any other kind of material. There was not available detailed cost records for any other project utilizing material other than aluminum pipe which could be used for comparison purposes. It may be concluded that the most significant cost advantages resulting from the utilization of aluminum pipe are the first cost of the material itself and the obvious cost advantage of being able to install the aluminum pipe material in relatively long lengths utilizing minimum effort resulting in minimum cost to lower the pipe into the trench rather than the necessity of having a separate piece of machinery to lift and lower heavier pipe into the trench.

Observation of construction procedures and comparison with projects utilizing other storm sewer material indicate that the degree of advantage to the use of aluminum pipe from the standpoint of the material weight is somewhat proportional to the length of trench which can be excavated on a per day basis. Obviously in congested urban areas the amount of lineal footage of trench which can be excavated is not always controlled by the amount of pipe which can be placed but rather by the limitation imposed by existing underground utilities and traffic conditions. Some difficulty was encountered by workmen in placing and coupling bands on the helically corrugated pipe. However, these difficulties primarily involved use of insufficient length of bolts and difficulty aligning the coupling band to properly mesh with the helical corrugations on the pipe. An apparent disadvantage to the use of aluminum pipe is the comparative weakness of the pipe unit itself which is more easily damaged during construction procedures from general contact with the pipe by construction equipment, vandalism and caving trenches. It was observed that in certain areas the 20-foot long sections were a disadvantage because it was impossible to maintain a section of open trench of sufficient length to install the 20-foot long section due to poor soil conditions. However, this was the exception rather than the rule and occurred at locations where the excavation was deep and the soil was very unstable. All surfaces of the aluminum pipe which were constructed in contact with concrete manholes, inlets and other concrete appurtenances were coated with bitumastic material in order to eliminate any possible reaction between the concrete and aluminum.

Favorable comment was made by workmen relative to the ease of installing the longer length sections of aluminum pipe utilizing only two workmen with ropes to lower the pipes into the trench. Utilization of lengths shorter than the standard 20 foot length was accomplished by simply using a gasoline engine powered metal cutting blade hand saw to cut the pipe to the desired length. The sawing operation required only a minimal time and did not delay construction progress. This proved to be an advantage over other materials such as concrete or vitrified clay because of the difficulty and time required to cut those materials. Another obvious advantage to the use of aluminum pipe was the fact that slight alignment changes and grade changes could be accomplished by the utilization of heat shrinkable coupling bands which allowed as much as a 20° bend at the joints without sacrificing strength or water tightness. General handling of aluminum pipe from the time it arrives on the job site until the time it is installed into the ground is easier by virtue of its light weight.

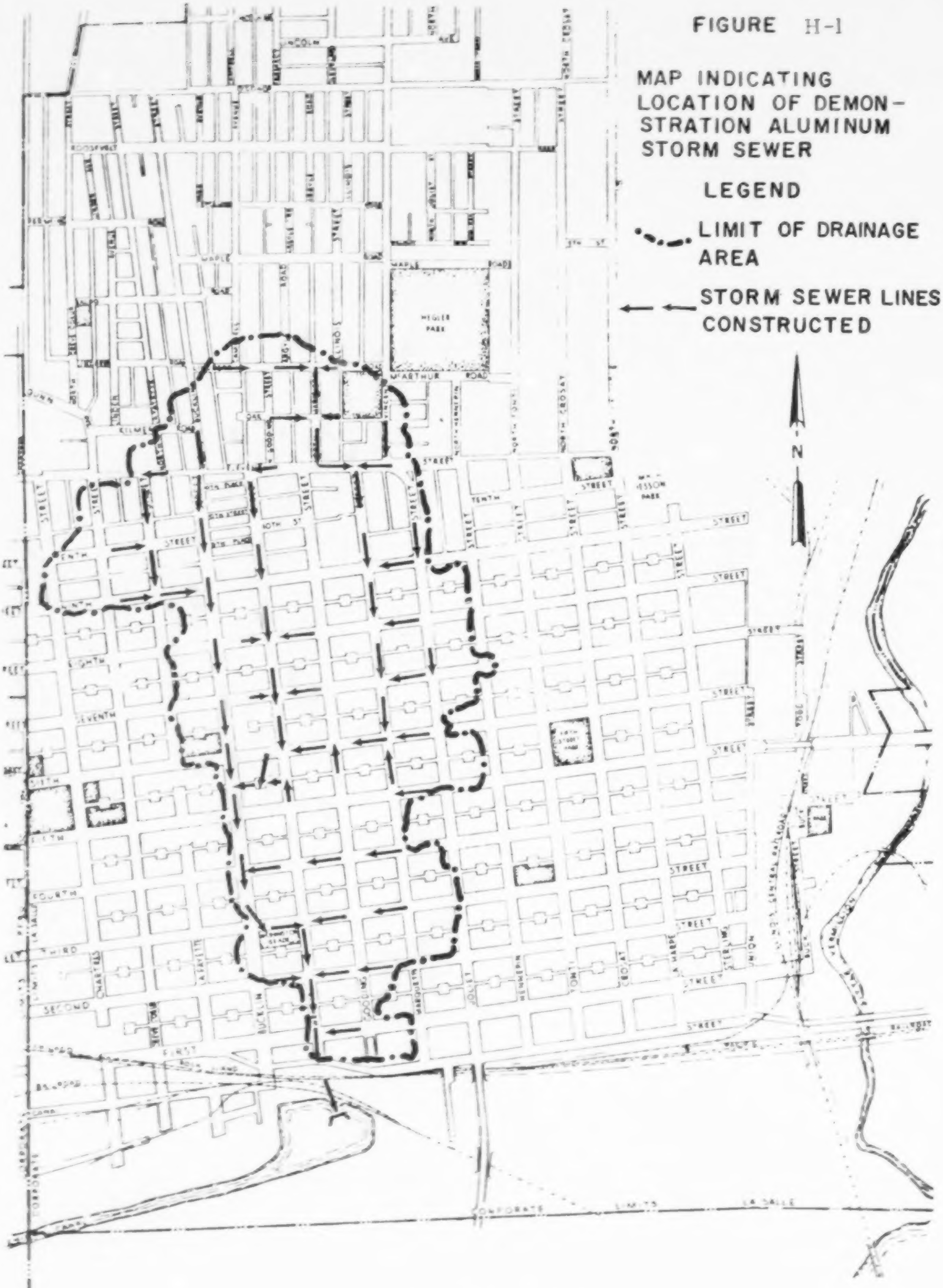


FIGURE H-1

MAP INDICATING LOCATION OF DEMONSTRATION ALUMINUM STORM SEWER

LEGEND
LIMIT OF DRAINAGE AREA
STORM SEWER LINES CONSTRUCTED
N
LINCOLN
ROOSEVELT
MAPLE
HEGLER PARK
McARTHUR ROAD
TENTH
STREET
EIGHTH
SEVENTH
SIXTH
FOURTH
THIRD
SECOND
FIRST
LA FAYETTE
BUCKLIN
GOODING
MARQUETTE
JOLIET
HENNEPIN
TONTI
CROSAT
LA HARPE
ILLINOIS CENTRAL RAILROAD
CORPORATE LIMITS LA SALLE

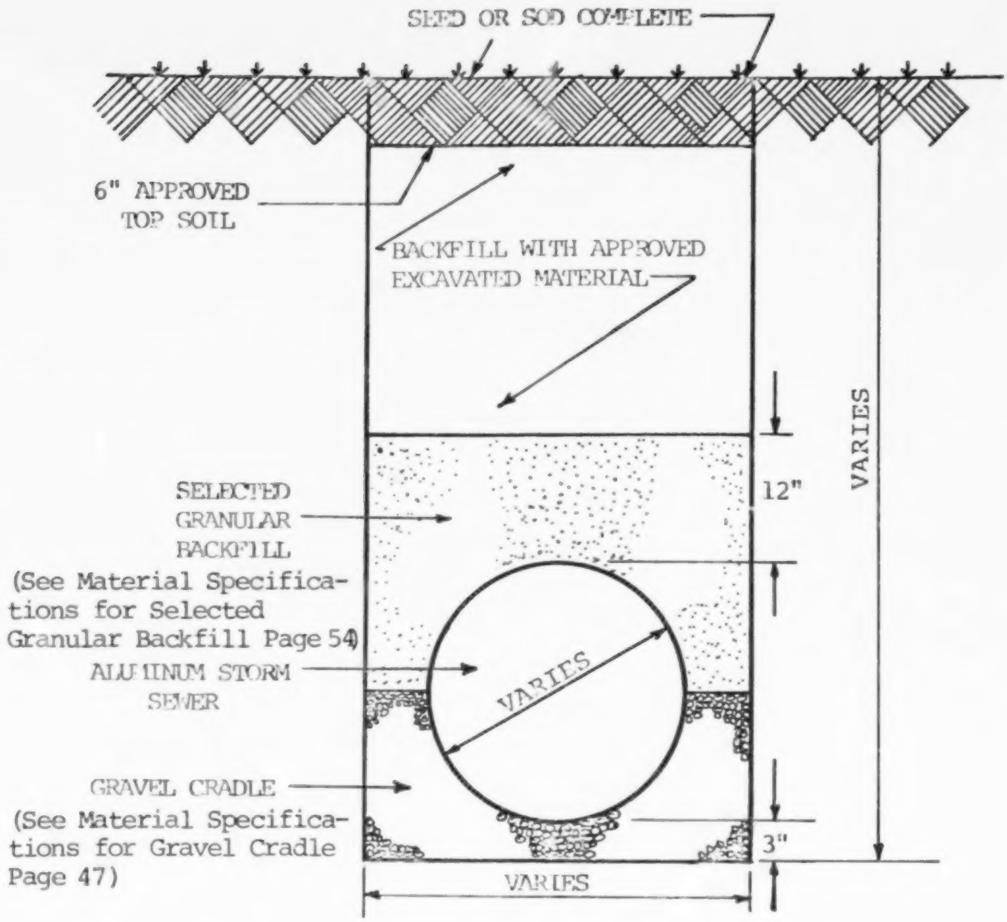

SEED OR SOD COMPLETE
6" APPROVED TOP SOIL
BACKFILL WITH APPROVED EXCAVATED MATERIAL
VARIES
12"
SELECTED GRANULAR BACKFILL
(See Material Specifications for Selected Granular Backfill Page 54)
ALUMINUM STORM SEWER
VARIES
GRAVEL CRADLE
(See Material Specifications for Gravel Cradle Page 47)
3"
VARIES

FIGURE H-2. TYPICAL TRENCH DETAIL - STANDARD 1 X 6 CORRUGATION OR 1/2 X 2 2/3 HELICAL CORRUGATION ALUMINUM PIPE CONSTRUCTION
Non-Hardsurfaced Areas

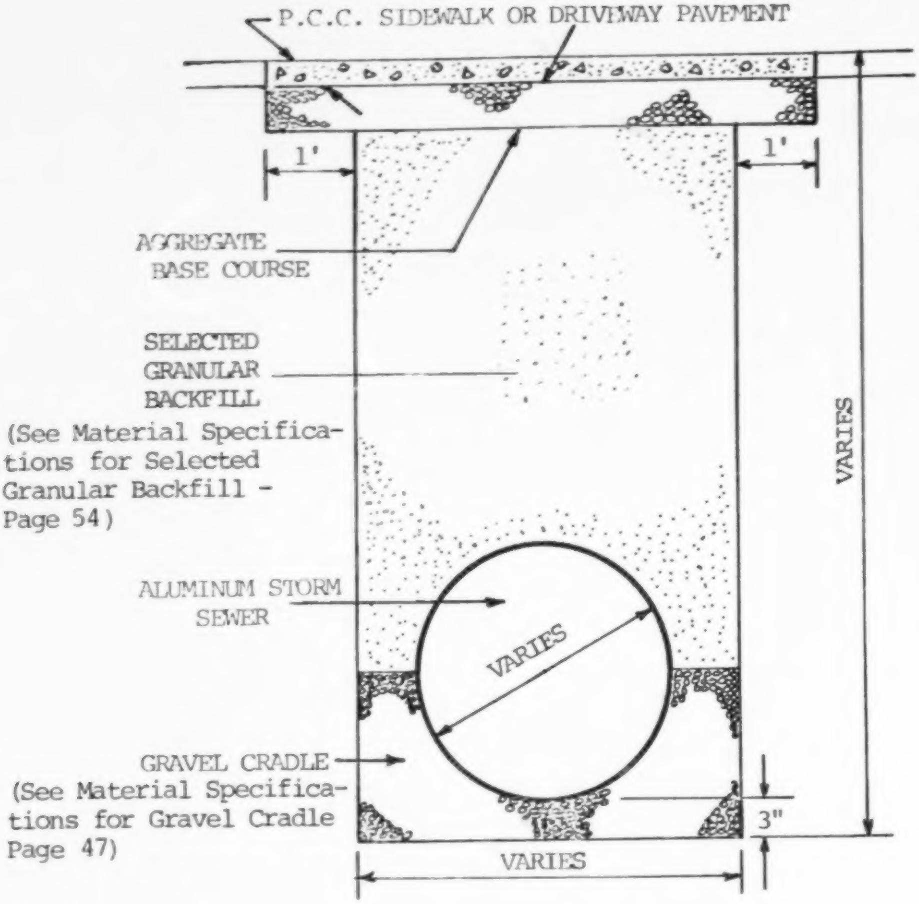

P.C.C. SIDEWALK OR DRIVEWAY PAVEMENT
1'
1'
AGGREGATE BASE COURSE
SELECTED GRANULAR BACKFILL
(See Material Specifications for Selected Granular Backfill - Page 54)
ALUMINUM STORM SEWER
VARIES
GRAVEL CRADLE
(See Material Specifications for Gravel Cradle Page 47)
3"
VARIES
VARIES

FIGURE H-3. TYPICAL TRENCH DETAIL - STANDARD 1 X 6 CORRUGATION OR 1/2 X 2 2/3 HELICAL CORRUGATION ALUMINUM PIPE CONSTRUCTION
Hard-Surfaced Areas

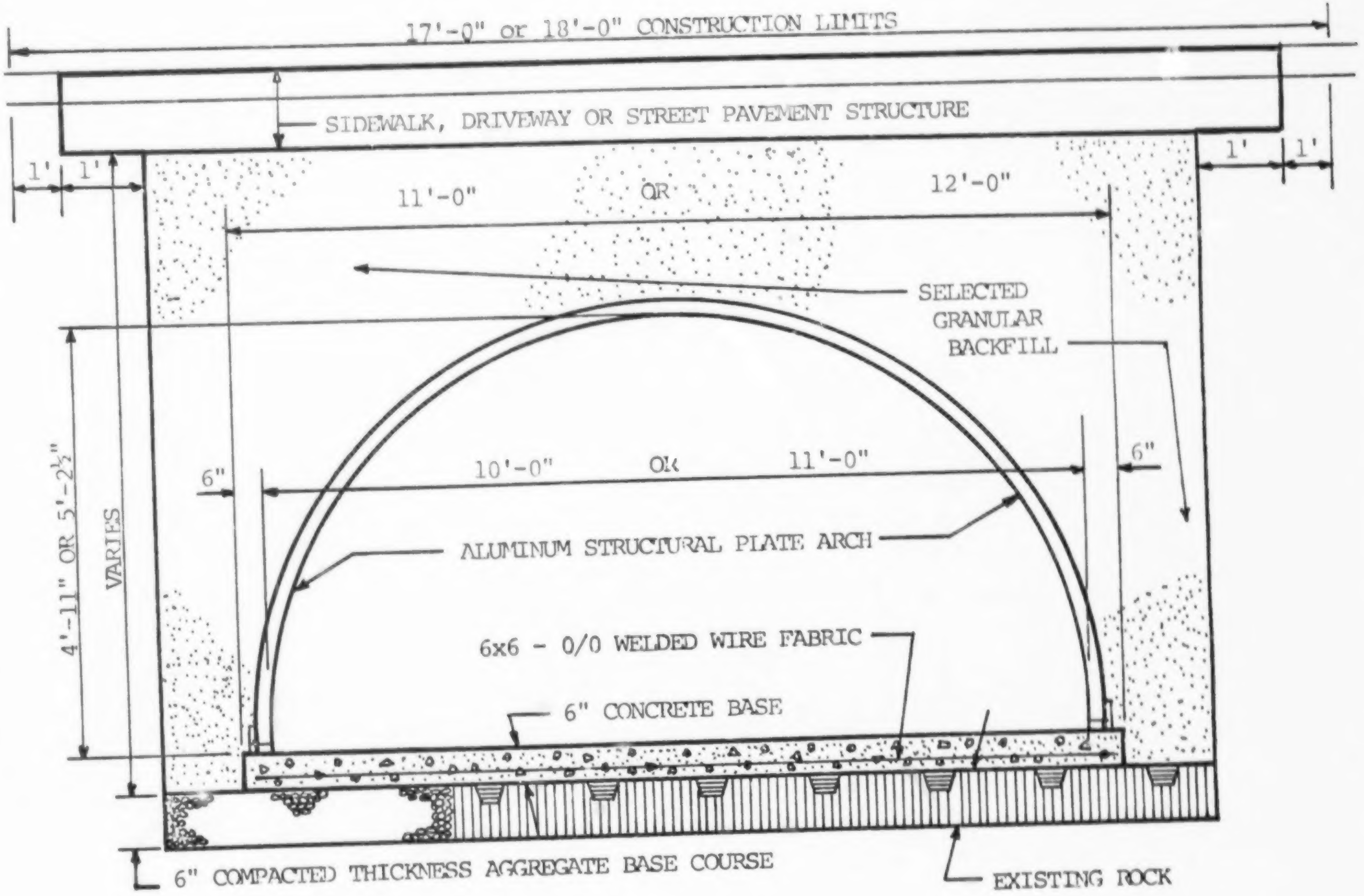

17'-0" or 18'-0" CONSTRUCTION LIMITS
SIDEWALK, DRIVEWAY OR STREET PAVEMENT STRUCTURE
1'
1'
1'
1'
11'-0"
OR
12'-0"
SELECTED
GRANULAR
BACKFILL
6"
10'-0"
OR
11'-0"
6"
4'-11" OR 5'-2½"
VARIES
ALUMINUM STRUCTURAL PLATE ARCH
6x6 - 0/0 WELDED WIRE FABRIC
6" CONCRETE BASE
6" COMPACTED THICKNESS AGGREGATE BASE COURSE
EXISTING ROCK

FIGURE H-4. TYPICAL TRENCH DETAIL - STRUCTURAL PLATE ARCH CONSTRUCTION

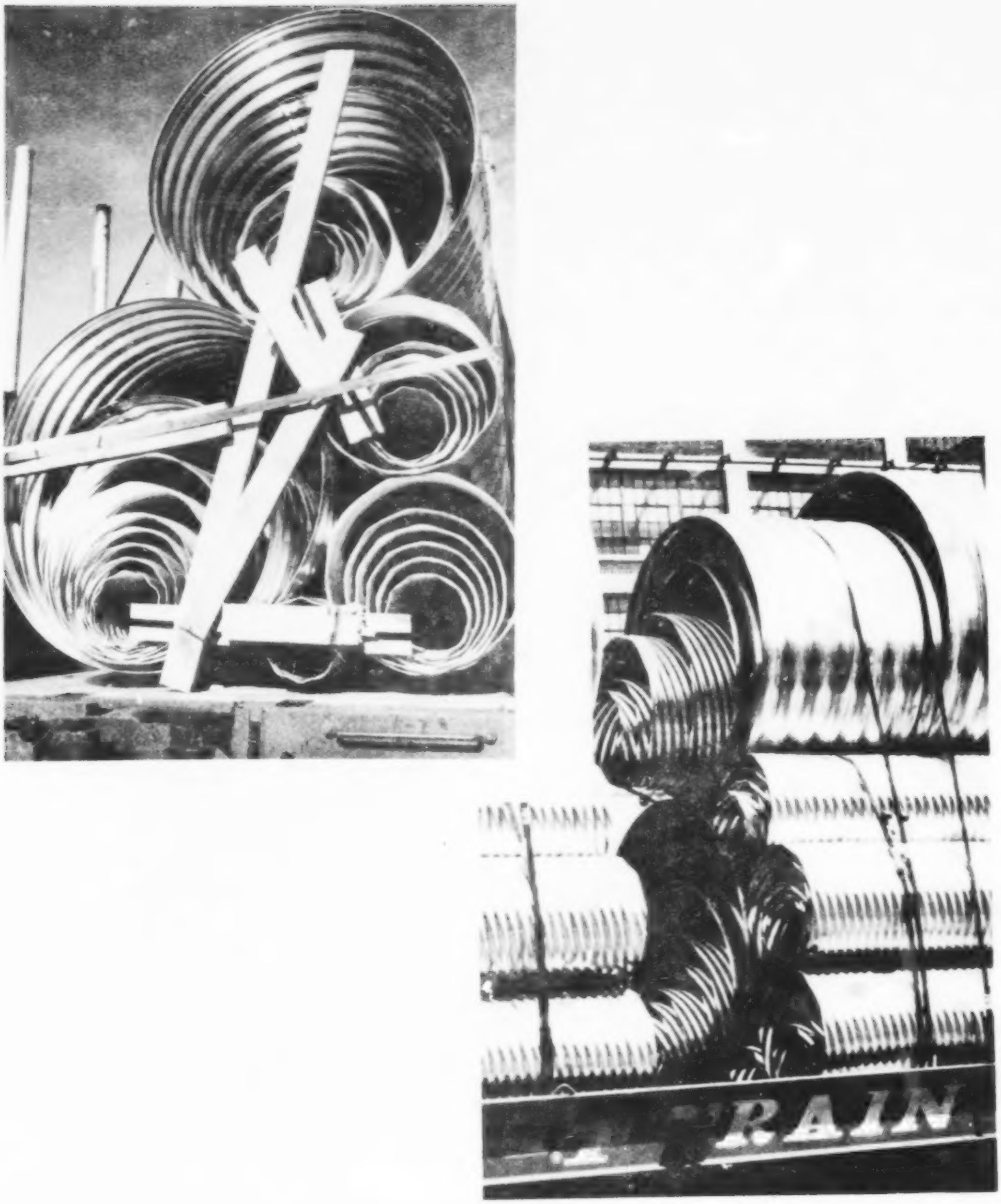
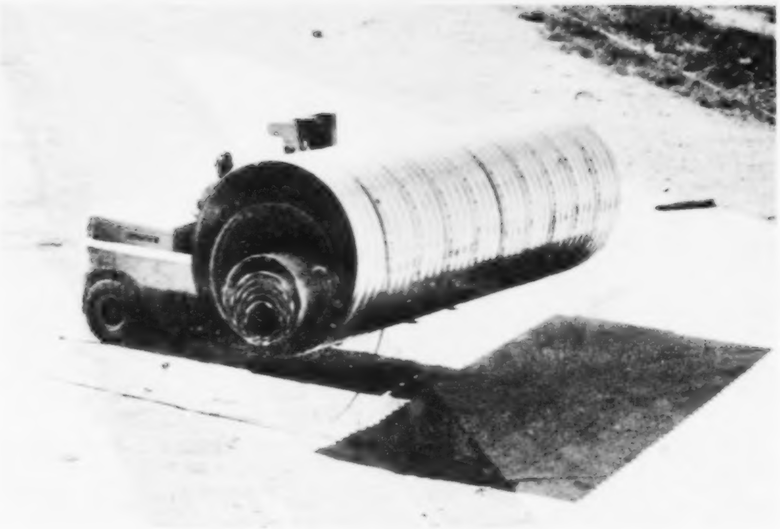


FIGURE H-5. "NESTED" PIPE DELIVERED ON RAILROAD CARS



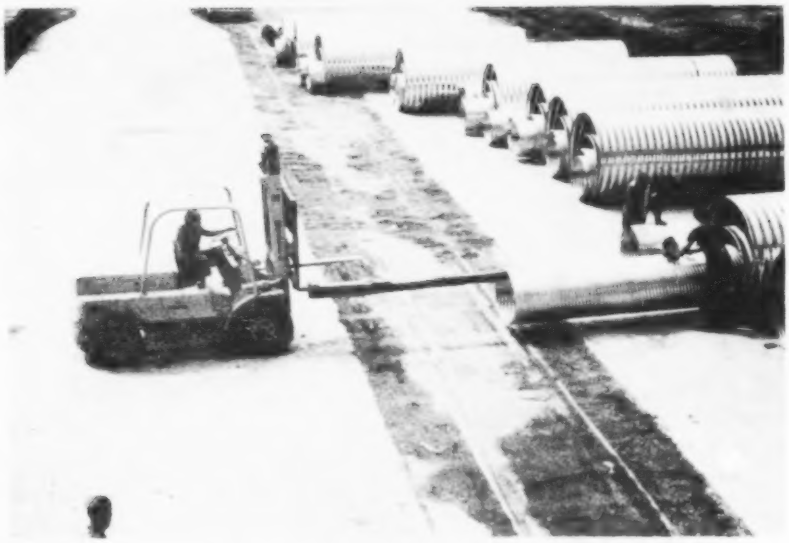


FIGURE H-6. DELIVERED PIPE BEING UNLOADED AND STORED

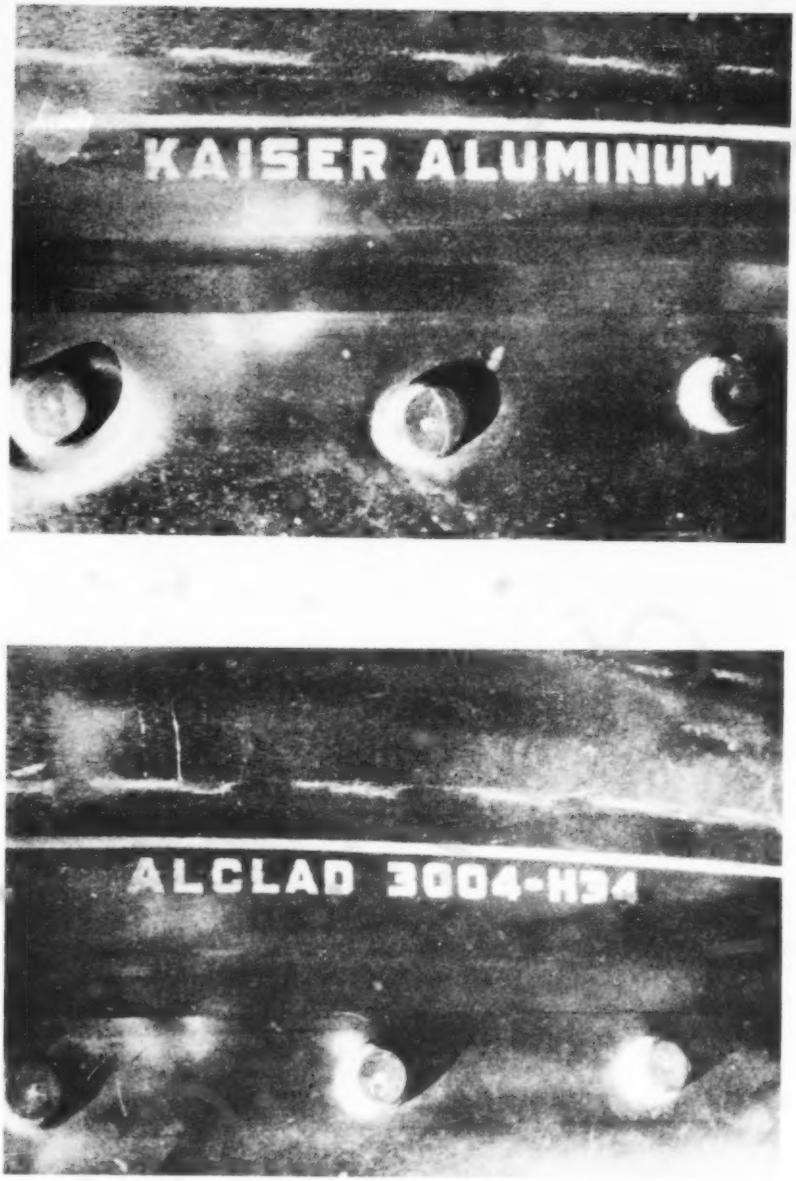
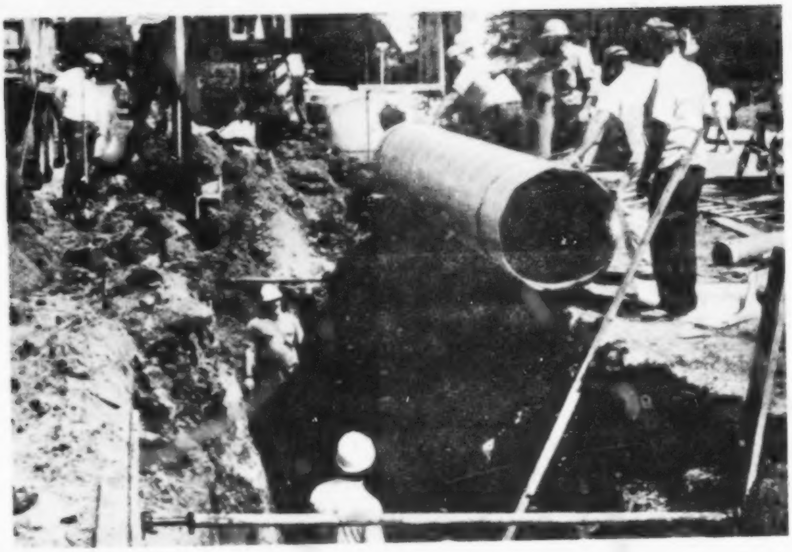

KAISER ALUMINUM
ALCLAD 3004-H34

FIGURE H-7. NAME AND NUMBER STAMPINGS ON DELIVERED PIPE



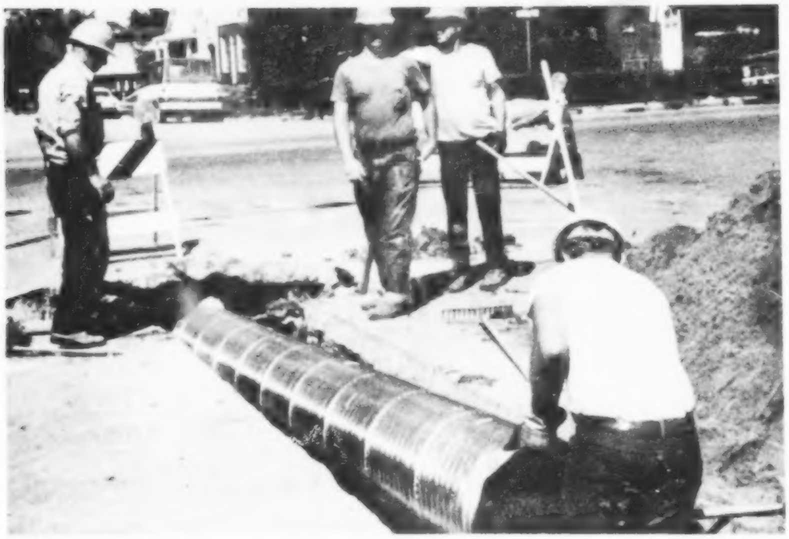


FIGURE H-8. PLACING ALUMINUM PIPE IN EXCAVATED TRENCH

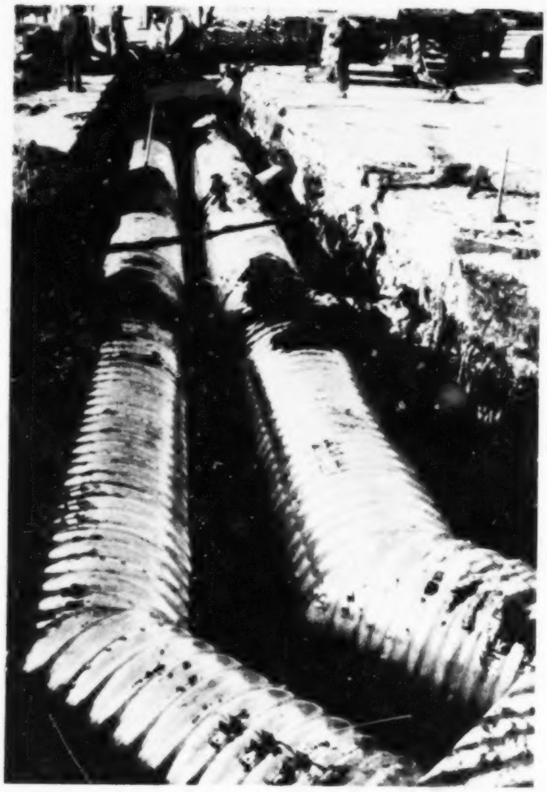


FIGURE H-9. PARALLEL ALUMINUM STORM SEWER PLACED IN SHALLOW EXCAVATION

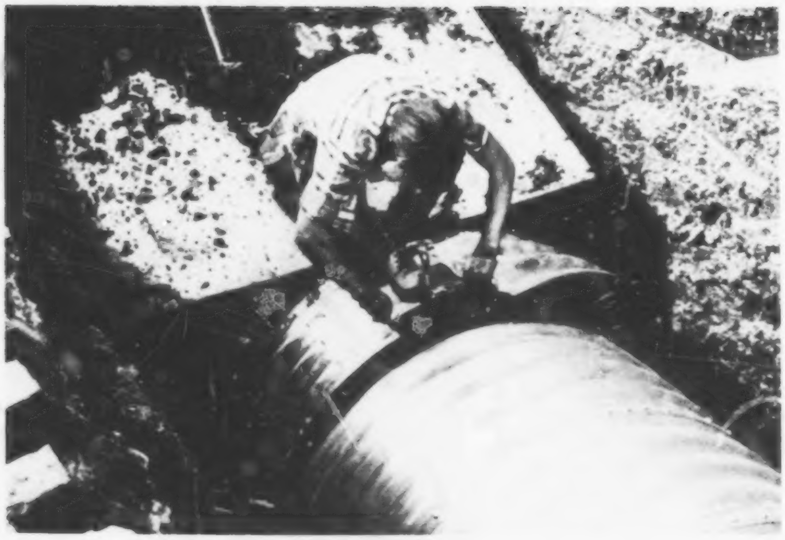
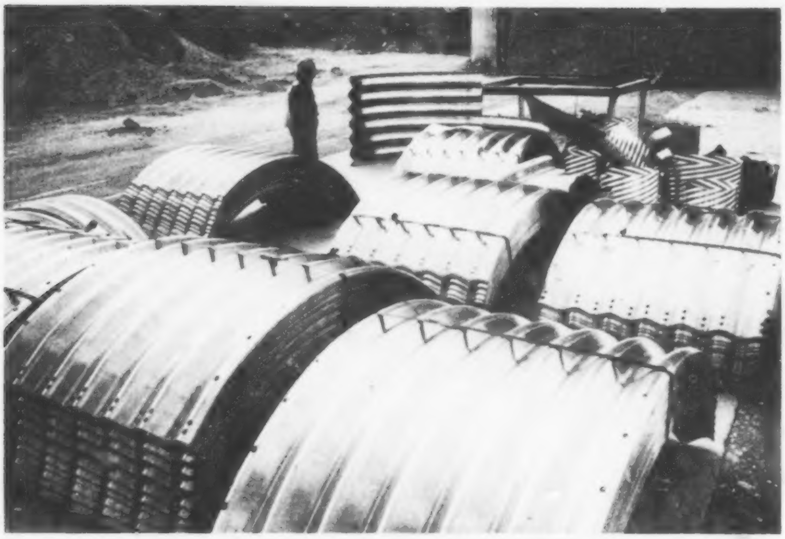


FIGURE H-10. PLACING ALUMINUM COUPLING BAND ON 42 INCH DIAMETER STANDARD CORRUGATION PIPE



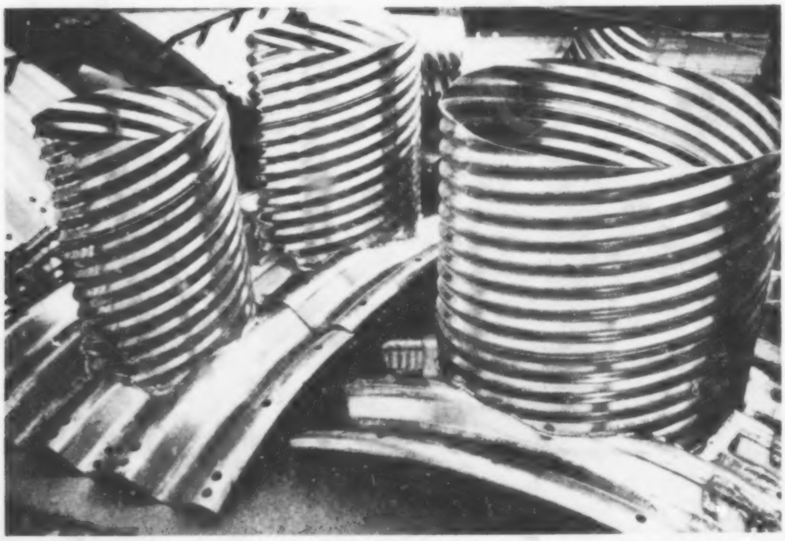


FIGURE H-11. STRUCTURAL PLATE ARCH SECTIONS
AND TAPPING SADDLES AT
CENTRAL STORAGE AREA

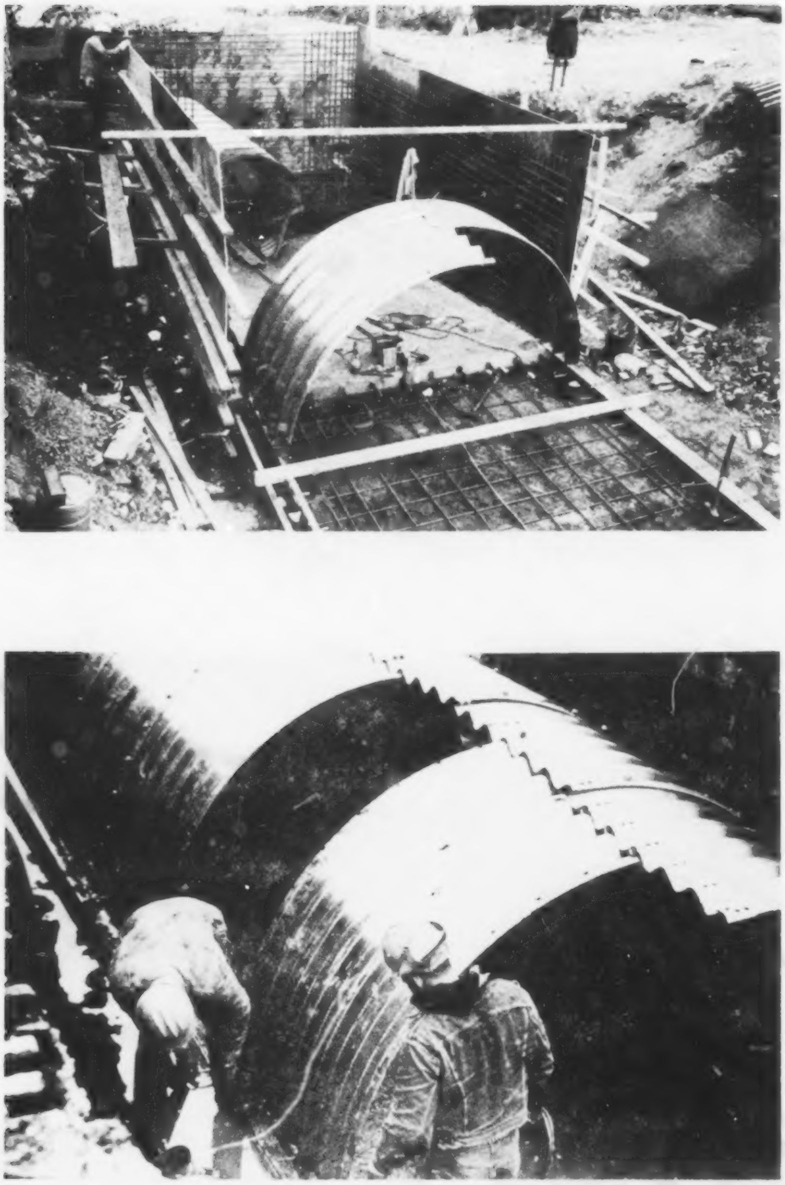


FIGURE H-12. ASSEMBLING STRUCTURAL PLATE ARCH

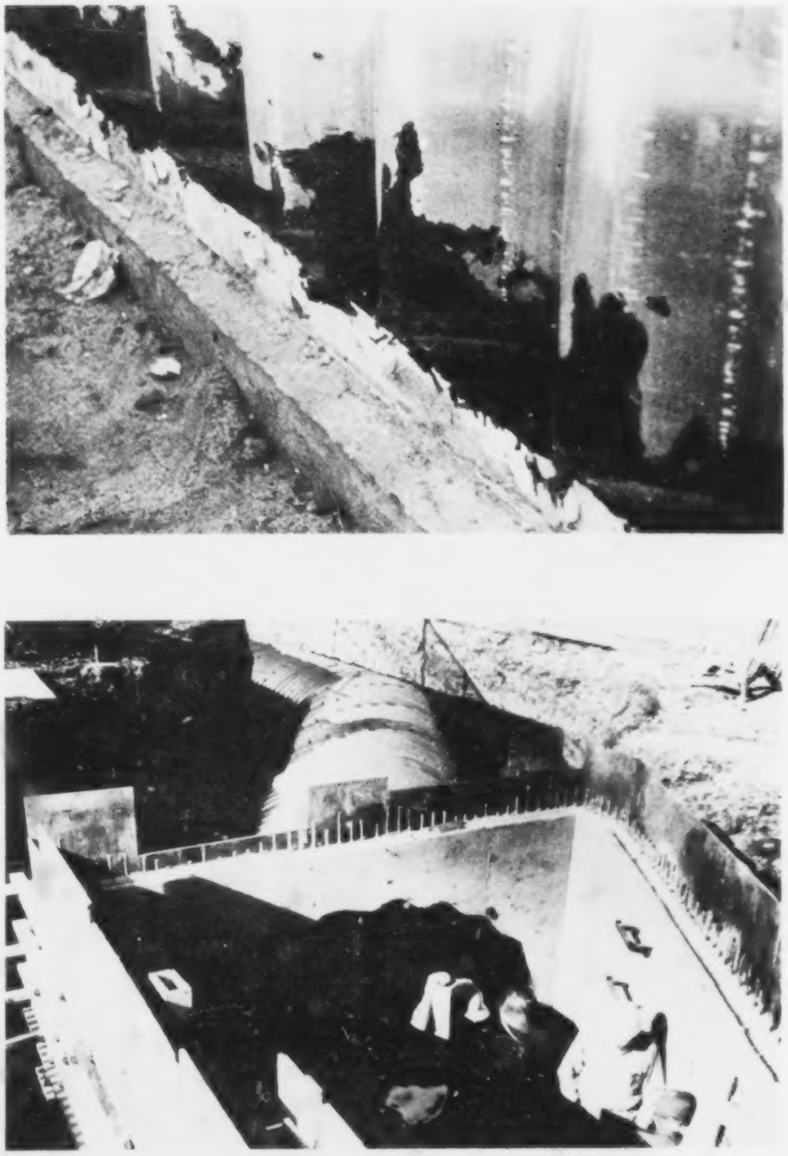


FIGURE H-13. DETAILS OF PLATE ARCH CONSTRUCTION

Upper Photo-Sealing of Corrugations with Bitumastic Material Between Aluminum Angle and Structural Plate Arch

Lower Photo-Connection of Structural Plate Arch to Reinforced Concrete Manhole Structure

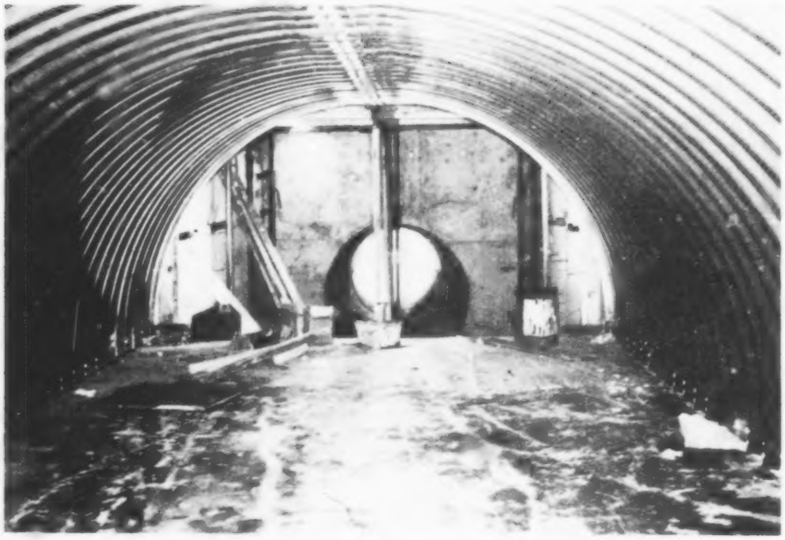


FIGURE H-14. INTERIOR VIEW-TRANSITION FROM STRUCTURAL PLATE ARCH SECTION TO CIRCULAR SECTION AT SPECIAL REINFORCED CONCRETE STRUCTURE

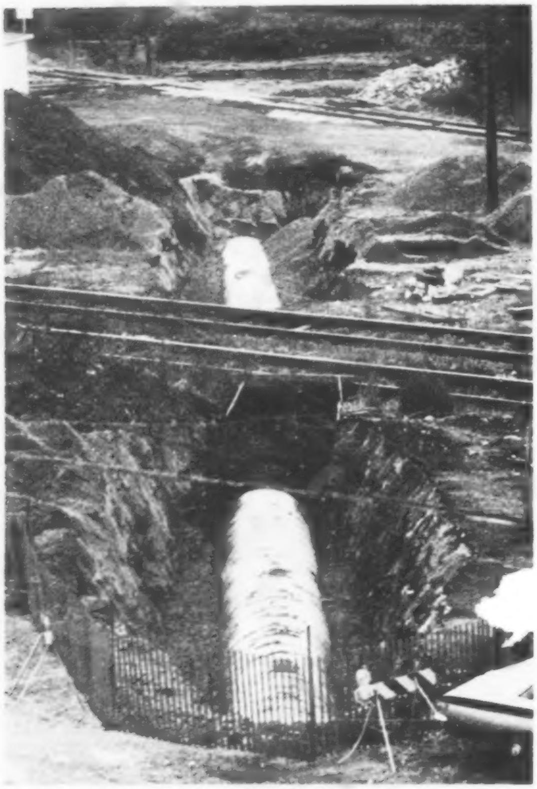


FIGURE H-15. CONNECTED DEMONSTRATION ALUMINUM STORM SEWER UNDER CRI & P AND CB & Q RAILROADS

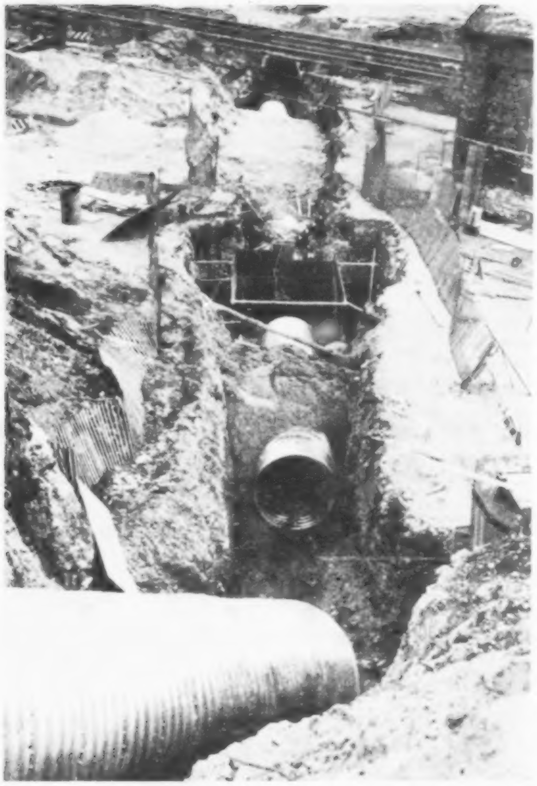


FIGURE H-16. PARTIALLY COMPLETED DEMONSTRATION ALUMINUM STORM SEWER UNDER CRI & P AND CB & Q RAILROADS

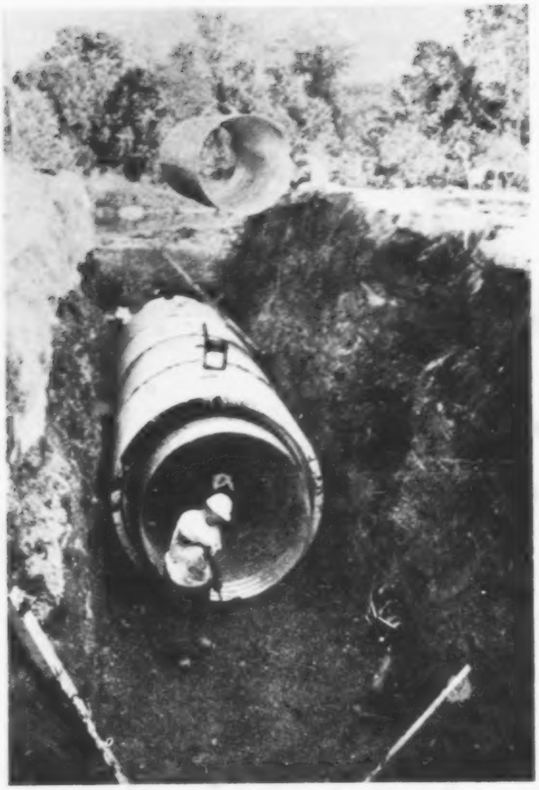


FIGURE H-17. 72" ALUMINUM SEWER CONSTRUCTED THROUGH REINFORCED CONCRETE "SLEEVE" UNDER CB & Q RAILROAD

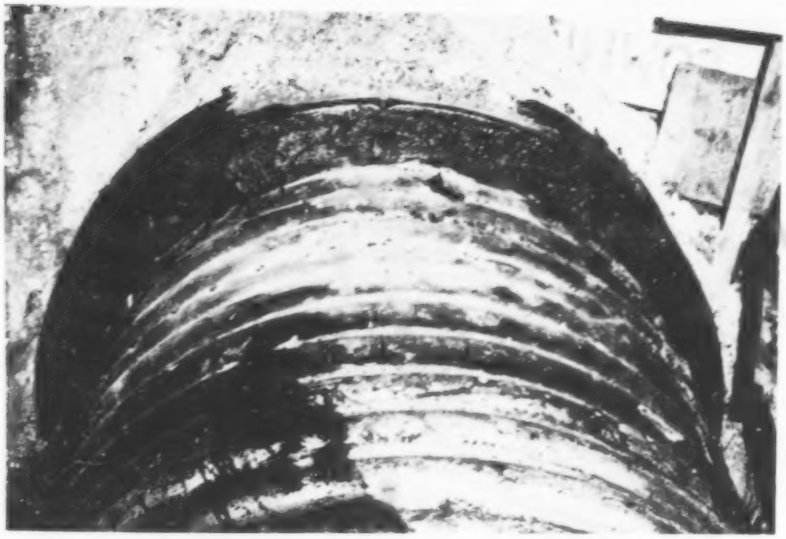


FIGURE H-18. BITUMASTIC SEAL OF VOID BETWEEN ASPHALT COATED 72" ALUMINUM SEWER AND RIBBED STEEL-TUNNEL UNDER CRI & P RAILROAD

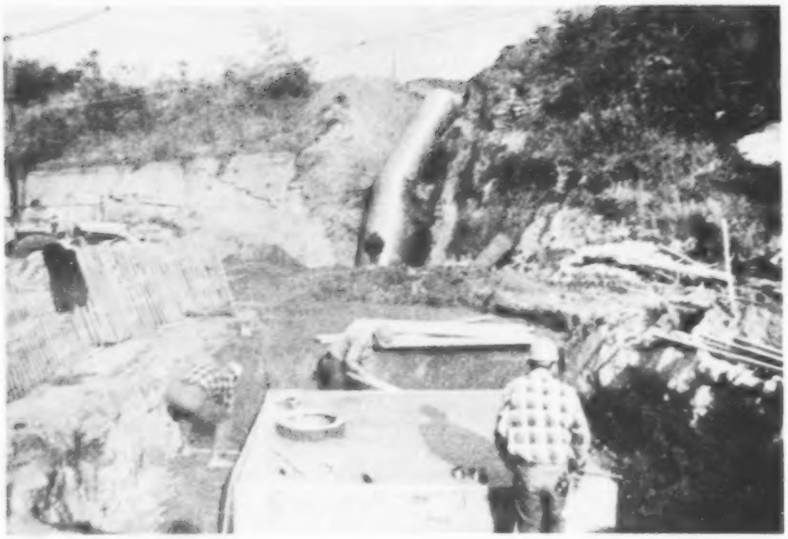
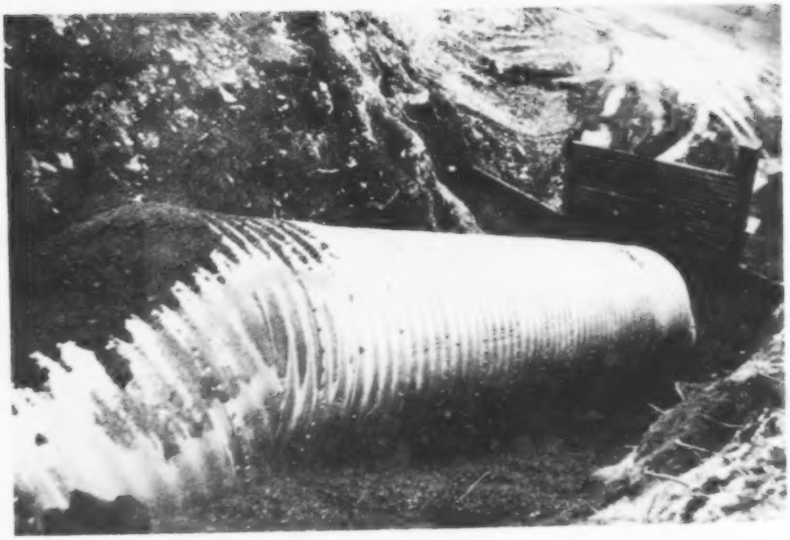


FIGURE H-19. DISTANT VIEW OF ASSEMBLED 66" DIAMETER STORM SEWER ON STEEP SLOPE



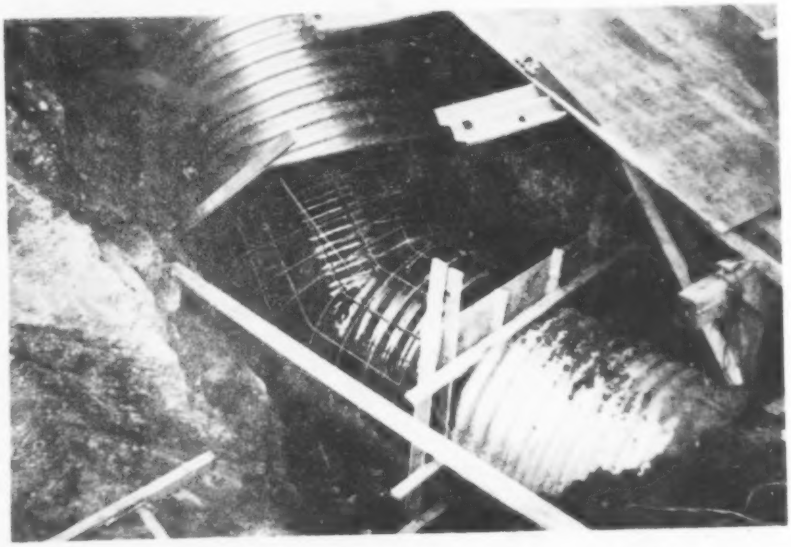


FIGURE H-20. 66" DIAMETER STORM SEWER ON STEEP SLOPE

Upper Photo-Assembled Section Looking From Top (North) to Bottom (South)

Lower Photo-Base Elbow Prior to Placing Concrete "Collar" to Resist Horizontal & Vertical Forces

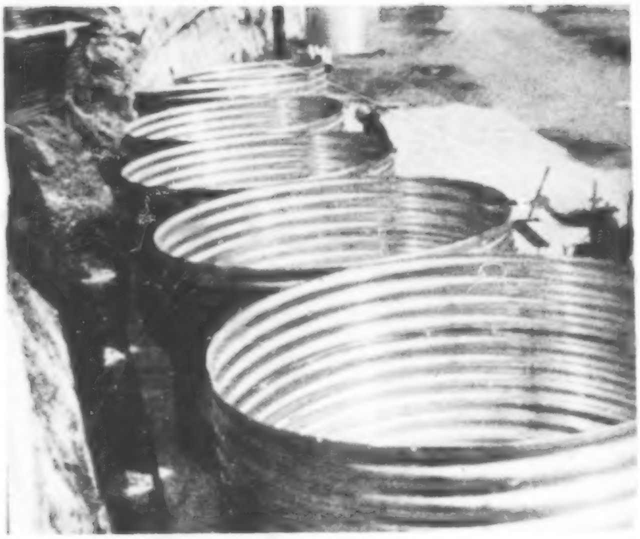
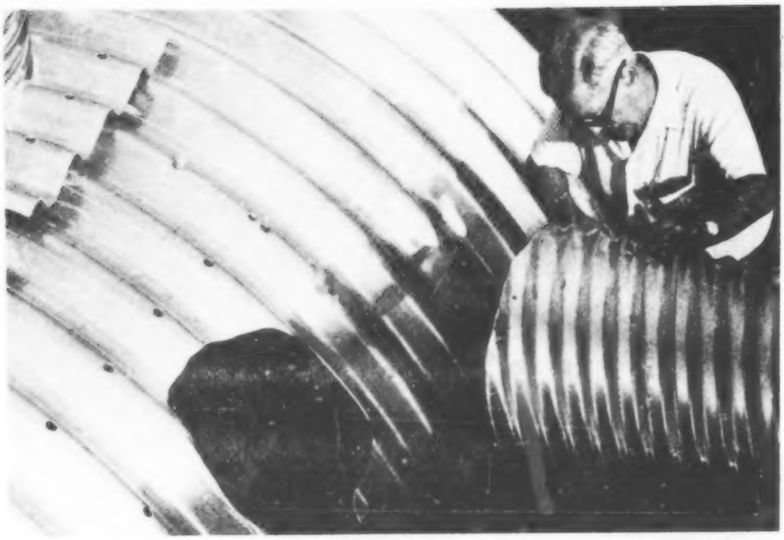


FIGURE H-21. CONSTRUCTING ALUMINUM "BIN" RETAINING WALL OVER BASE OF 66" DIAMETER STORM SEWER ON STEEP SLOPE



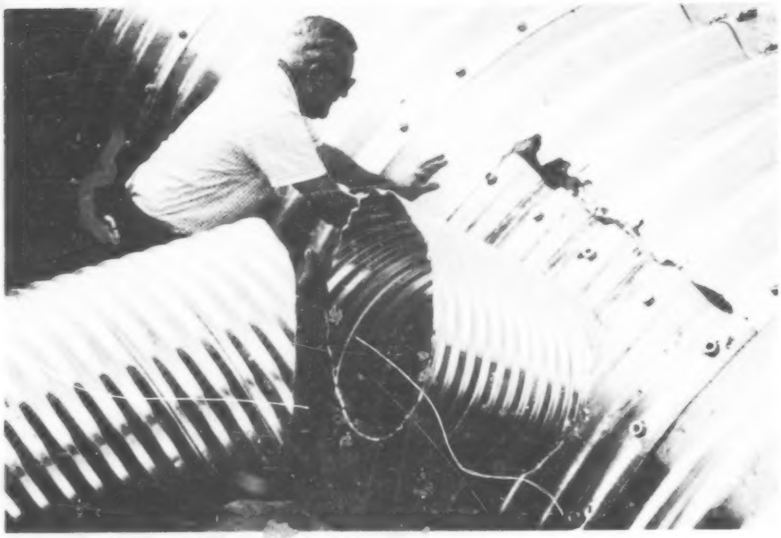


FIGURE H-22. SEQUENCE OF CONNECTION UTILIZING ALUMINUM TAPPING SADDLE AND JOINT UTILIZING HEAT SHRINKABLE COUPLING BAND

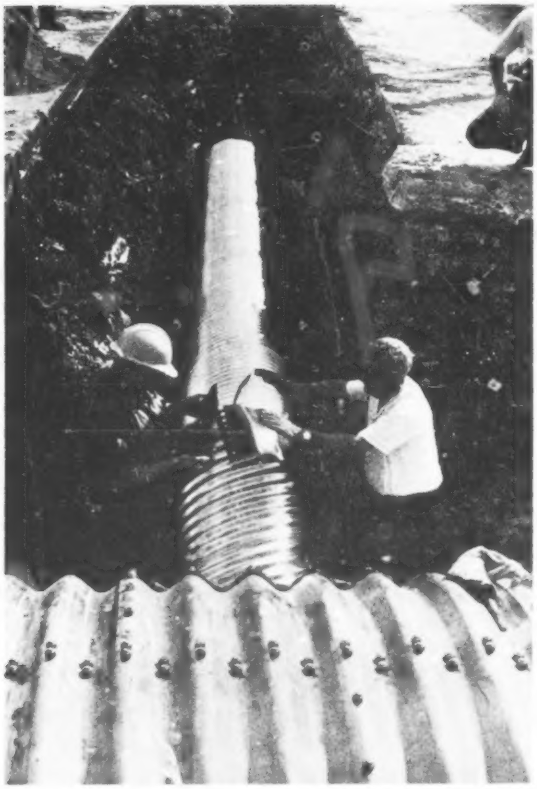


FIGURE H-23. SEQUENCE OF CONNECTION UTILIZING ALUMINUM TAPPING SADDLE AND JOINT UTILIZING HEAT SHRINKABLE COUPLING BAND

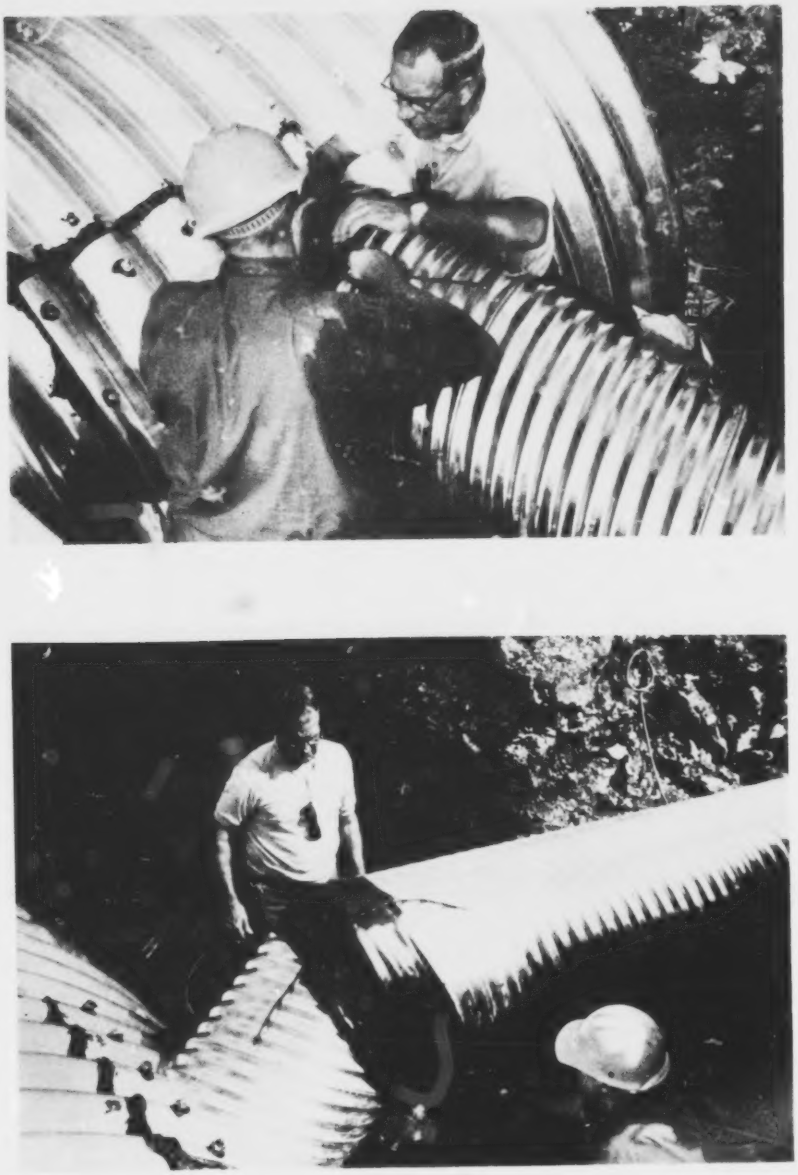


FIGURE H-24. SEQUENCE OF CONNECTION UTILIZING ALUMINUM TAPPING SADDLE AND JOINT UTILIZING HEAT SHRINKABLE COUPLING BAND

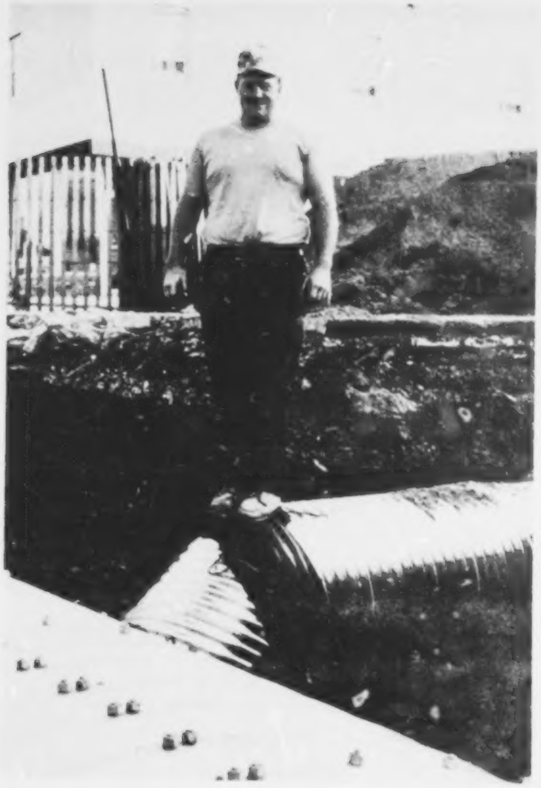


FIGURE H-25. SEQUENCE OF CONNECTION UTILIZING ALUMINUM TAPPING SADDLE AND JOINT UTILIZING HEAT SHRINKABLE COUPLING BAND

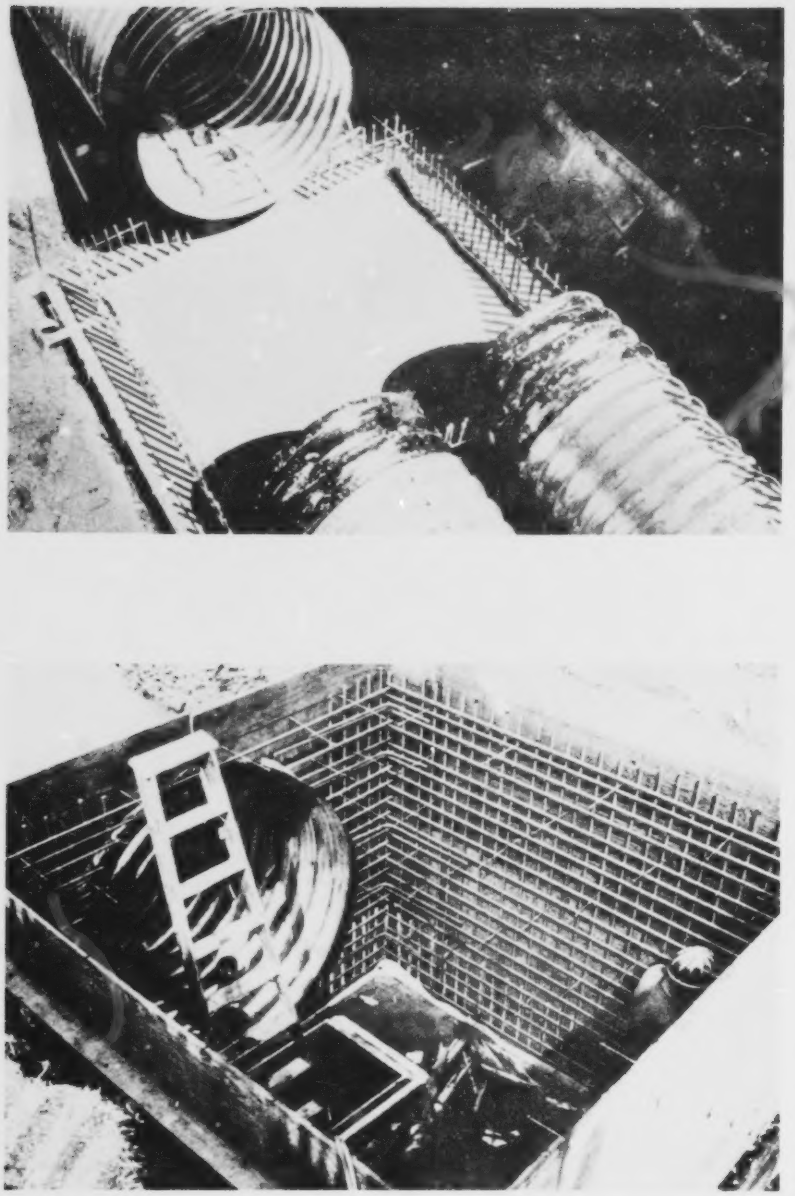


FIGURE H-26. CONSTRUCTION OF REINFORCED CONCRETE MANHOLE STRUCTURES

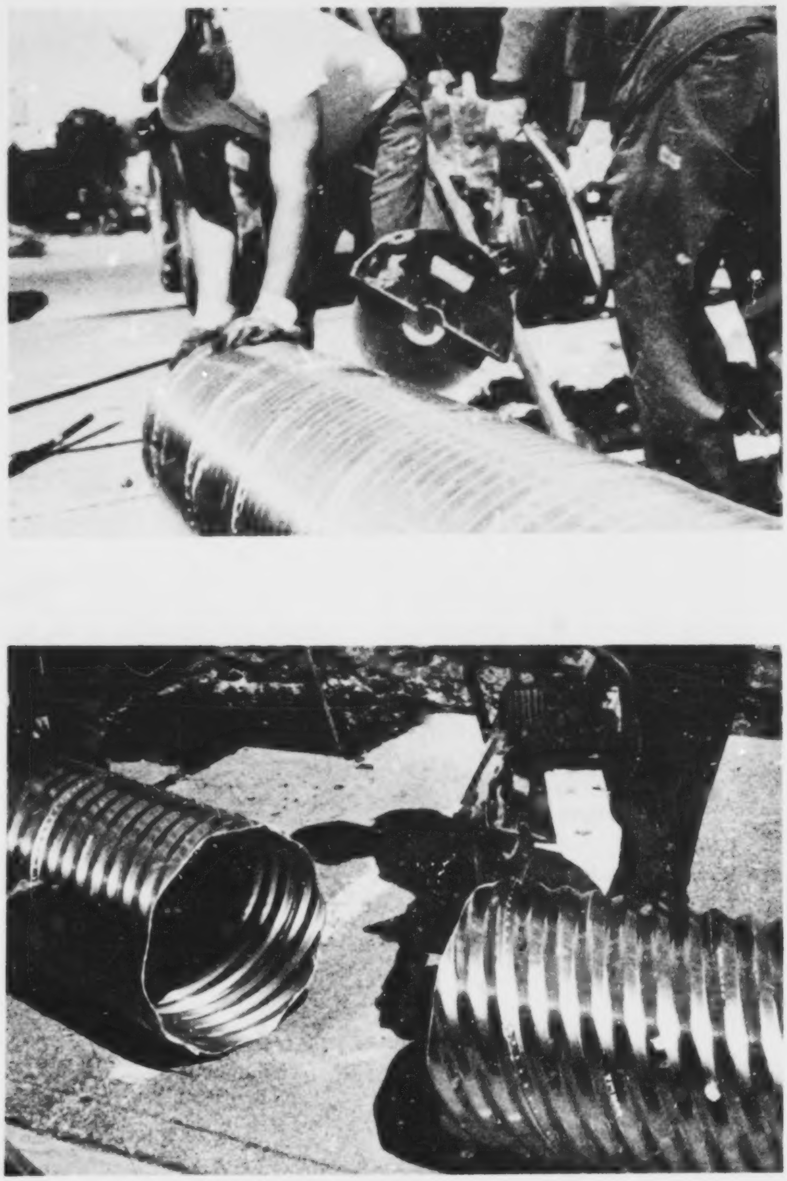


FIGURE H-27. CUTTING 18" HELICAL CORRUGATION PIPE WITH POWER SAW

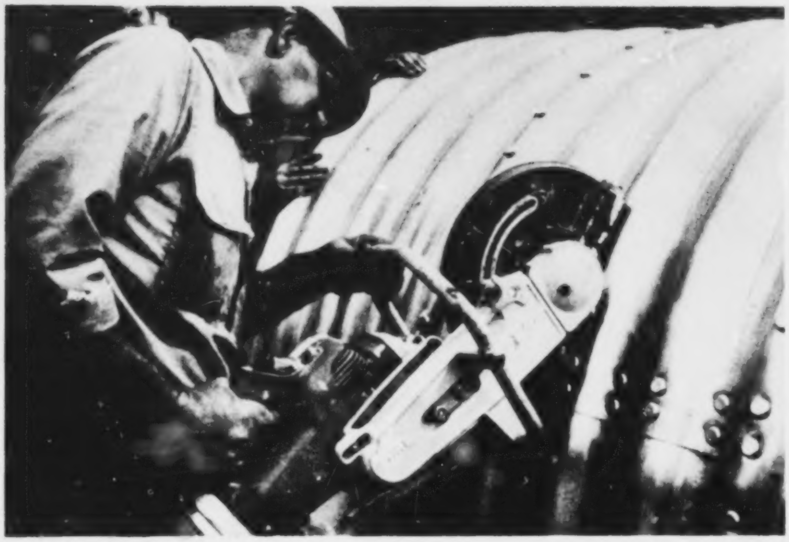


FIGURE H-28. CUTTING STANDARD CORRUGATION 72" PIPE WITH POWER SAW

SECTION I

POST-CONSTRUCTION EVALUATION

BACKGROUND

After completion of the LaSalle aluminum storm drain system in 1973, inspection tours have been conducted annually (1973, 1974, 1975, 1976). The inspections were attended by personnel from Chamlin & Associates, Consulting Engineers, Peru, Illinois, and Kaiser Aluminum, suppliers of the pipe material, as well as representatives from Illinois State Highway Department and City of LaSalle.

After each of the annual inspections, reports were prepared jointly by Kaiser Center for Technology and Chamlin & Associates, Inc. describing visual inspection and laboratory evaluation of samples removed.

The following summarizes significant points included in these reports.

SUMMARY

After three years of service the aluminum storm drain system (alloys clad 3004 and 5052) is in excellent condition. The extent of corrosion found has an insignificant affect on the structural integrity of the arch and pipe structures.

All clad 3004 alloy sampled throughout the storm drain system is performing in a predictable manner i.e. extent of corrosion, if any, is limited to the cladding. Corrosion attack from water side (interior of pipe) is virtually non-existent. Corrosion from soil side has subsided since first inspection.

Other areas of specific interest are as follows:

Mechanical - Buckling Inclined Portion of 66 Inch 1 x 6 Below 1st and Wright Streets

The initial inspection revealed several buckled areas in a sharply inclined portion of 66 inch 1 x 6 pipe. This occurred during construction and concern was expressed regarding its continuing movement when subjected to subsequent external loads and extreme water velocities. Close visual inspection as well as a series of comparative photos indicate that there has been no movement in the section after the first year's inspection. (See Figure I-2 for comparative photos).

Corrosion - Dissimilar Materials

During the second inspection corrosion was observed in sections of 72 inch 1 x 6 pipe that passed through a steel tunnel liner under CRI & P railroad tracks. Although the two metals were thought to be insulated from one another to prevent galvanic corrosion, it was surmised that the two structures were in contact. Potential readings were taken during the 1974 and 1975 inspections and results verified the possibility of dissimilar metal corrosion in this particular area. Recommendations have been made on the required cathodic protection.

Isolated Pit Blisters in 5052 Alloy

The first (1973) inspection revealed an unusual phenomenon in the isolated areas of the 5052 alloy structural plate arch. In these areas, numerous pinhole perforations were exuding a gelatinous corrosion product. This was noted and ear marked for careful observation during the second inspection. As expected, very few changes occurred during the following year. Much of the "weeping" seen during the first (1973) inspection seemed to have subsided. It was speculated that perhaps an aggressive material had leached through the previous backfill and attacked the soil side of the structure during the first year of operation. During the 1974 inspection, it was decided therefore to monitor a section of affected material by blocking out a 1½' x 3' area, counting and circling the corrosion blisters.

The third annual inspection conducted in August of 1975, clearly confirmed theory put forth during the 1974 inspection. Virtually all of the gelatinous corrosion product had dried up indicating cessation of corrosion activity. No new blisters were observed and those circled in the monitored study remained unchanged.

Rust Colored Scale Deposits

The initial inspection reported extensive presence of a red-orange rust colored gelatinous deposit at bolt holes along the bottom of arch structure between 1st and 3rd Streets and Wright and at location along Bucklin. This was identified as an amorphous iron oxide material which converts into hematite (Fe_2O_3) with calcining. There was no evidence of corrosion underneath these scale deposits. The 1974 inspection reported substantially less presence of this material and except for isolated locations it had virtually disappeared by the 1975 inspection.

EVALUATION OF ALUMINUM PIPE COMPARED TO OTHER MATERIALS

The post construction evaluation based upon a comparison of corrugated aluminum pipe (CAP), corrugated steel pipe (CSP), and reinforced concrete pipe (RCP) with regard to material cost and operational expenses was made utilizing available published information regarding list prices of the various materials as follows:

Items Included in Total Cost of Storm Sewer Pipe

(1) Material cost at producing location.

(2) Freight to job site.

(3) Labor and equipment (if necessary) to unload at trench site.

(4) Labor and equipment to dig trench.

(5) Labor and equipment (if necessary) to install pipe in trench.

(6) Backfill and/or bedding material.

(7) Labor and equipment to place backfill and/or bedding material.

Assumptions required to compare installed costs of various storm sewer materials.

(1) Material suppliers normally discount from list price, particularly if the design engineer specifies alternate materials. Assume all materials listed in Table I-1 are quoted at 35% discount, FOB plant.

(2) Assume corrugated steel pipe is furnished in 20' lengths and all bands cost same as 1½ Lin.Ft. of pipe. Therefore, band cost adds 7½% to pipe cost. Assume corrugated aluminum pipe is furnished in 40' lengths and all bands cost same as 1½ feet of pipe. Therefore, band cost adds 3-3/4% to pipe cost. Assume concrete pipe furnished in 8' lengths. No bands required.

(3) Freight to job site depends on distance and quantity of pipe that can be carried as determined by legal weight and size. Assume all producing locations are 100 miles from job site and cost per loaded mile is $1.50 per mile or $150 per

trip. Legal size truckload is considered 8' wide x 8' high x 40' long. Legal pay load is considered 42,000 pounds.

(4) Although bare aluminum pipe is normally nested for shipment if a variety of sizes are required on the project this savings will be ignored on cost of freight computed in Table I-2. Conversely this results in savings in cost to unload truck of aluminum pipe at job site if unnesting not required and this is considered in Table I-3.

(5) Assume pipes up to 400 pounds each can be "manhandled" into trench without equipment. Pipe with weight per piece 400# to 4,000# can be handled with light duty equipment @ cost of $15.00/hour, and pipe weighing 4,000# to 20,000# can be handled with heavy duty equipment @ cost of $25.00/hour. These rates do not include manpower (See Table I-4).

(6) Assume items (5), (6), and (7) of items included in total costs of storm sewer pipe (above) remain the same for all materials. This assumption is valid for the following reasons:

a. Because of more favorable hydraulic "friction" factors in concrete pipe, the resulting diameter of concrete pipe is normally less than the diameter of corrugated metal pipe for a given hydraulic carrying capacity.

b. The difference in diameter indicated above is essentially offset by the fact that concrete pipe has a greater wall thickness.

Due to the additional wall thickness of concrete, the trench must be slightly deeper to maintain the same flow line. Although concrete does not require as much care in backfilling as corrugated metal pipe it does require more care in bedding so that short lengths and heavy weight do not result in "joint tipping" thus reducing hydraulic capacity. Longer pipe length and the lighter weight result in more effective "bridging" of soft spots in the bedding. Also lighter pipe that can be placed in the trench faster allows for less open trench time reducing the danger of trench wall collapse prior to backfill which results in savings in both excavating and backfilling.

(7) Cost of items (5), (6), and (7) are not included in Cost Summary Table 5 since these are considered equal for various pipe materials. Also it varies considerably from site to site depending on trench depth, stability of trench walls, etc.

FIELD INSPECTION AND LABORATORY EVALUATIONS

Inspection procedures have been standardized to enable comparisons to be made from one year to the next.

Each year metal samples consisting of 2½" diameter coupon and soil are removed in the proximity of those taken during the previous inspection as well as selecting new locations. The holes are covered with mastic sealer and aluminum patch and fastened with stainless steel screws. Locations are identified with different color for each year - blue - 1975, red - 1974, and orange - 1973.

Pipe to soil and pipe to water potentials are measured with a Cu/Cu S_{04} reference electrode (Miller Potential Meter 1A). Soil samples are removed and placed in a quart size plastic container. Figure I-1 identifies samples taken during each inspection.

Laboratory evaluation consisted of the following procedure:

Determining soil pH and minimum resistivity using State of California Division of Highways Method 643 B.

Chemical analyses of representative soil and water samples.

All metal samples photographed both sides before and after cleaning. They are then sectioned at deepest appearing attack and mounted for metallographic cross section. Figure I-5 shows 5 x photo micrographs of samples taken in most recent inspection.

EXPECTED SERVICE LIFE

The expected service life of a storm drain system, regardless of material used is naturally a key consideration and of vital concern among engineers involved in design of drainage systems. The aluminum industry last addressed this question in a jointly sponsored paper which was presented to the then Highway Research Board in 1969. At this point in time an additional 7 years of data from field inspections are available to draw upon which results in a total of 17 years in place service at many sites.

TABLE I-1. TYPICAL PIPE SECTION LIST PRICES

Corrugated				Smooth	
Size	Ga.	CAP *	CSP *	Size	RCP *
18"	16	$ 6.85	$ 7.80	15"	$ 4.95
24"	14	10.70	12.02	21"	6.80
30"	14	13.00	14.69	27"	10.50
36"	12	21.75	23.80	33"	15.90
48"	12	29.90	32.77	46"	24.10
60"	10	51.05	54.87	54"	39.15
72"	10	63.90	68.48	66"	54.60
84"	8	90.35	96.17	78"	84.65

* Cost in dollars per lineal foot.

NOTES:

1. List price not available for asbestos cement pipe producers of that product normally quote on job by job basis.

2. Price shown for concrete pipe is next smaller commercially available size than corrugated pipe due to hydraulic considerations.

3. Corrugated steel pipe price includes asphalt coating.

4. Reinforced concrete pipe is Class III, Tongue and Groove Mortar Joint.

5. (a) CAP prices obtained from published list prices by Kaiser Aluminum & Chemical Sales (Illinois, Indiana, Kentucky, and Michigan prices) effective 10-1-74.
   (b) CSP prices obtained from published list prices by Wheeling Corrugating Company of Louisville, Kentucky and Clark County Metal Products of Marshall, Illinois (identical prices) effective 10-75.
   (c) RCP prices obtained from published list prices by the Cincinnati Concrete Pipe Company of Cincinnati, Ohio effective 10-75.

TABLE I-2. FREIGHT COST

Corrugated Pipe			Concrete Pipe		
Size	Ft. per Load	Fgt. Cost/Ft.	Size	Ft. per Load	Fgt. Cost/Ft.
18	1120	$ .13	15	272	$ .55
24	640	.23	21	176	.85
30	360	.42	27	128	1.17
36	160	.94	33	88	1.71
48	160	.94	42	56	2.69
60	80	1.88	54	32	4.70
72	40	3.75	66	24	6.26
84	40	3.75	78	16	9.38

* In all cases total quantity of pipe available per load is determined by cube for metal pipe and by weight for concrete pipe.

TABLE I-3. UNLOADING COST

CAP			CSP			RCP		
Size	Ft/Ld	Cost/Ft.	Size	Ft/Ld	Cost/Ft.	Size	Ft/Ld	Cost/Ft.
18	1120	$.02	18	1120	$ .04	15	272	$ .20
24	640	.03	24	640	.07	21	176	.31
30	360	.06	30	360	.13	27	128	.43
36	160	.13	36	160	.28	33	88	.63
48	160	.13	48	160	.28	42	56	.98
60	80	.25	60	80	.56	54	32	1.72
72	40	.50	72	40	1.13	66	24	2.29
84	40	.50	84	40	1.13	78	16	3.43

NOTES:

1. For corrugated aluminum pipe, assume 2 men @ $10.00/hour rate will unload truck in 1 hour per average load without equipment.

2. For corrugated steel pipe assume 3 men @ $10.00/hour rate plus light duty crane @ $15.00/hour will unload truck in 1 hour per average load.

3. For reinforced concrete pipe assume 3 men @ $10.00/hour rate plus heavy duty crane @ $25.00/hour will unload truck in 1 hour per average load.

TABLE I-4. INSTALLATION COST

CAP			CSP			RCP		
Size	Wgt/Pc (40' long)	Cost/Ft	Size	Wgt/Pc (20' long)	Cost/Ft	Size	Wgt/Pc (8' long)	Cost/Ft
18	187	$.17	18	380	$1.38	15	1224	$3.44
24	308	.17	24	480	1.38	21	1864	3.44
30	384	.17	30	720	1.38	27	2640	3.44
36	639	.69	36	860	1.38	33	3680	3.44
48	848	.69	48	1500	1.38	42	5880	8.13
60	1393	.69	60	2280	3.25	54	9040	8.13
72	1666	.69	72	3260	3.25	66	12912	8.13
84	2310	.69	84	3800	3.25	78	16800	8.13

NOTES:

1. For pieces weighing up to 400# assume 2 men @ rate of $10.00/hour can install each piece in 20 minutes without equipment.

2. For pieces weighing 400# to 4,000# assume 4 men @ rate of $10.00/hour, 1 man hooks up lift - 1 operates crane and 2 men work in ditch, can install each piece in 30 minutes with light duty equipment @ cost of $15.00/hour.

3. For pieces weighing over 4,000# assume 4 men at rate of $10.00/hour, 1 man hooks up lift - 1 operates crane and 2 men work in ditch, can install each piece in 60 minutes with heavy duty equipment @ cost of $25.00/hour.

4. Above costs include labor and equipment to install pipe in trench only.

TABLE I-5. MATERIAL COST COMPARISON

	CAP		CSP		RCP	
Item	Size	Cost/Ft.	Size	Cost/Ft.	Size	Cost/Ft.
Material (List-35%)	18	$ 4.45	18	$ 5.07	15	$ 3.22
Connecting Bands		.17		.38		–
Freight		.13		.13		.55
Unloading		.02		.04		.20
Installation		.17		1.38		3.44
		$ 4.94		$ 7.00		$ 7.41
Material (List-35%)	24	$ 6.95	24	$ 7.83	21	$ 4.42
Connecting Bands		.26		.59		–
Freight		.23		.23		.85
Unloading		.03		.07		.31
Installation		.17		1.38		3.44
		$ 7.64		$10.10		$ 9.02
Material (List-35%)	30	$ 8.45	30	$ 9.55	27	$ 6.83
Connecting Bands		.32		.72		–
Freight		.42		.42		1.17
Unloading		.06		.13		.43
Installation		.17		1.38		3.44
		$ 9.42		$12.20		$11.87
Material (List-35%)	36	$14.14	36	$15.47	33	$10.34
Connecting Bands		.53		1.16		–
Freight		.94		.94		1.71
Unloading		.13		.28		.63
Installation		.69		1.38		3.49
		$16.43		$19.23		$16.17
Material (List-35%)	48	$19.44	48	$21.30	42	$15.67
Connecting Bands		.73		1.60		–
Freight		.94		.94		2.69
Unloading		.13		.28		.98
Installation		.69		1.38		8.13
		$21.93		$25.50		$27.47

continued

TABLE I-5 (continued)

	CAP		CSP		RCP	
Item	Size	Cost/Ft.	Size	Cost/Ft.	Size	Cost/Ft.
Material (List-35%)	60	$33.18	60	$35.66	54	$24.45
Connecting Bands		1.24		2.67		-
Freight		1.88		1.88		4.70
Unloading		.25		.56		1.72
Installation		.69		3.25		8.13
		$37.24		$44.02		$39.00
Material (List-35%)	72	$41.54	72	$44.51	66	$35.49
Connecting Bands		1.56		3.34		-
Freight		3.75		3.75		6.26
Unloading		.50		1.13		2.29
Installation		.69		3.25		8.13
		$48.04		$55.98		$52.17
Material (List-35%)	84	$58.73	84	$62.51	78	$55.08
Connecting Bands		2.20		4.69		-
Freight		3.75		3.75		9.38
Unloading		.50		1.13		3.43
Installation		.69		3.25		8.13
		$65.87		$75.33		$76.02
Grand Total		$211.51		$249.36		$239.13
Ave. Higher Cost than CAP				18%		13%

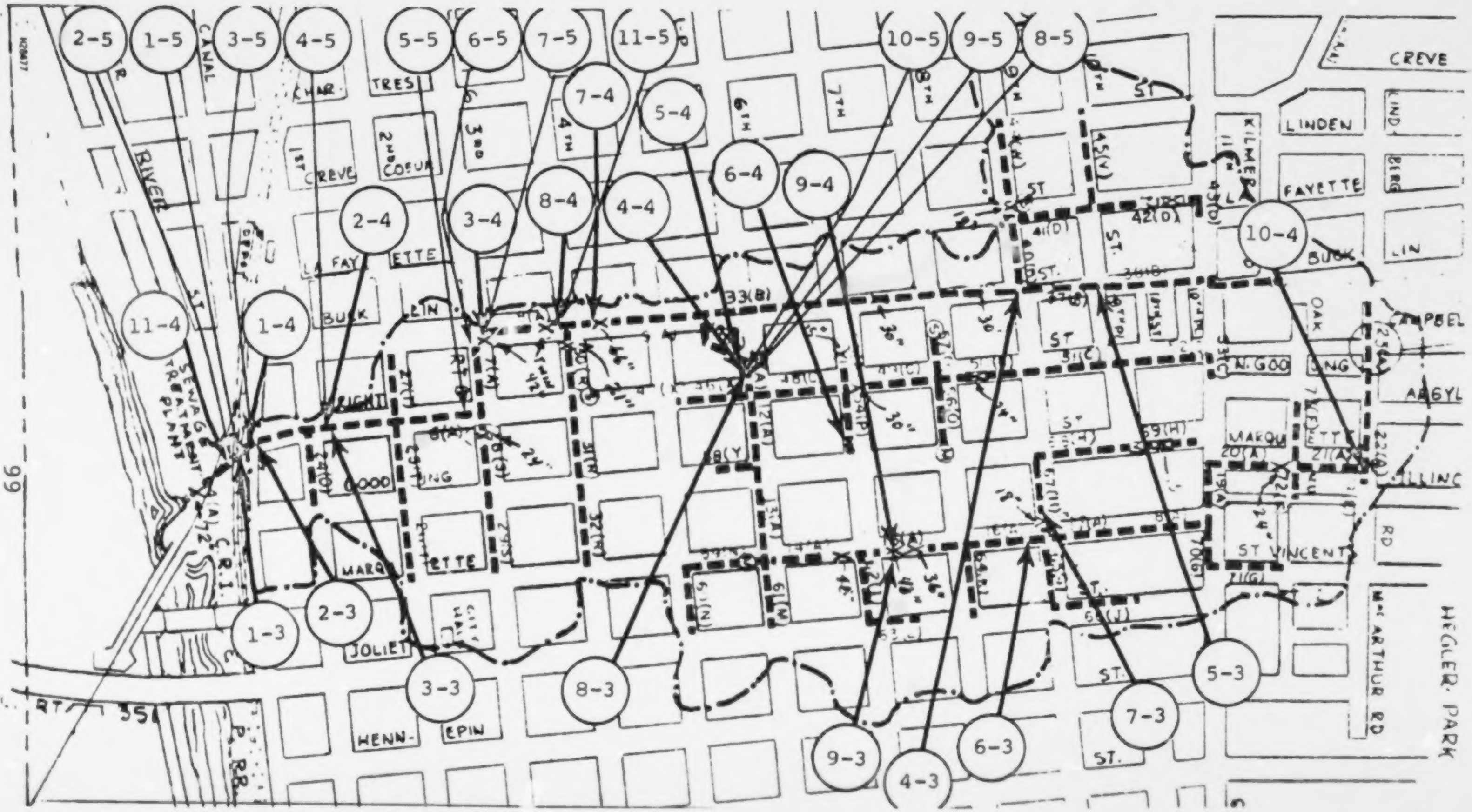
Notes:

1. For pieces weighing up to 400# assume 2 men @ rate of $10.00/hour can install each piece in 20 minutes without equipment.

2. For pieces weighing 400# to 4,000# assume 4 men @ rate of $10.00/hour, 1 man hooks up lift - 1 operates crane and 2 men work in ditch, can install each piece in 30 minutes with light duty equipment @ cost of $15.00/hour.

3. For pieces weighing over 4,000# assume 4 men at rate of $10.00/hour, 1 man hooks up lift - 1 operates crane and 2 men work in ditch, can install each piece in 60 minutes with heavy duty equipment @ cost of $25.00/hour.

4. Above costs include labor and equipment to install pipe in trench only.



2-5
1-5
3-5
4-5
5-5
6-5
7-5
11-5
10-5
9-5
8-5
7-4
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6-4
9-4
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8-4
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1-4
1-3
2-3
3-3
8-3
9-3
4-3
6-3
7-3
5-3
CANAL
RIVER
ST
CHAR.
TRES
1ST
CREVE
2ND
COEUR
3RD
4TH
6TH
7TH
8TH
9TH
10TH
LA FAY
ETTE
BUCK
LIN
SEWAGE TREATMENT PLANT
C.R.I.
RT 351
P. R.R.
JOLIET
HENN-
EPIN
MARQ
ETTE
GOOD
ING
RIGHT
CITY HALL
33(B)
66"
TWIN 42"
30"
36"
48"
24"
18"
72"
KILMER
LINDEN
FAYETTE
CREVE
LIND
BERG
BUCK
LIN
OAK
N. GOO
ING
CAMPBEL
ARGYL
ILLINC
MARQU
ETTE
ST VINCENT
MC ARTHUR RD
RD
HEGLER PARK
42(D)
43(D)
45(Y)
41(D)
20(A)
21(A)
22(A)
23(A)
19(A)
70(G)
71(G)
59(H)
67(H)

FIGURE I-1. ALUMINUM STORM DRAIN SYSTEM - LASALLE, ILLINOIS

Location of 1st, 2nd and 3rd (1973, 1974 and 1975) inspection sites and samples

i.e. -- First identification digit - individual sample number;
Second digit year (#3=1973, #4=1974 and #5=1975 inspection)

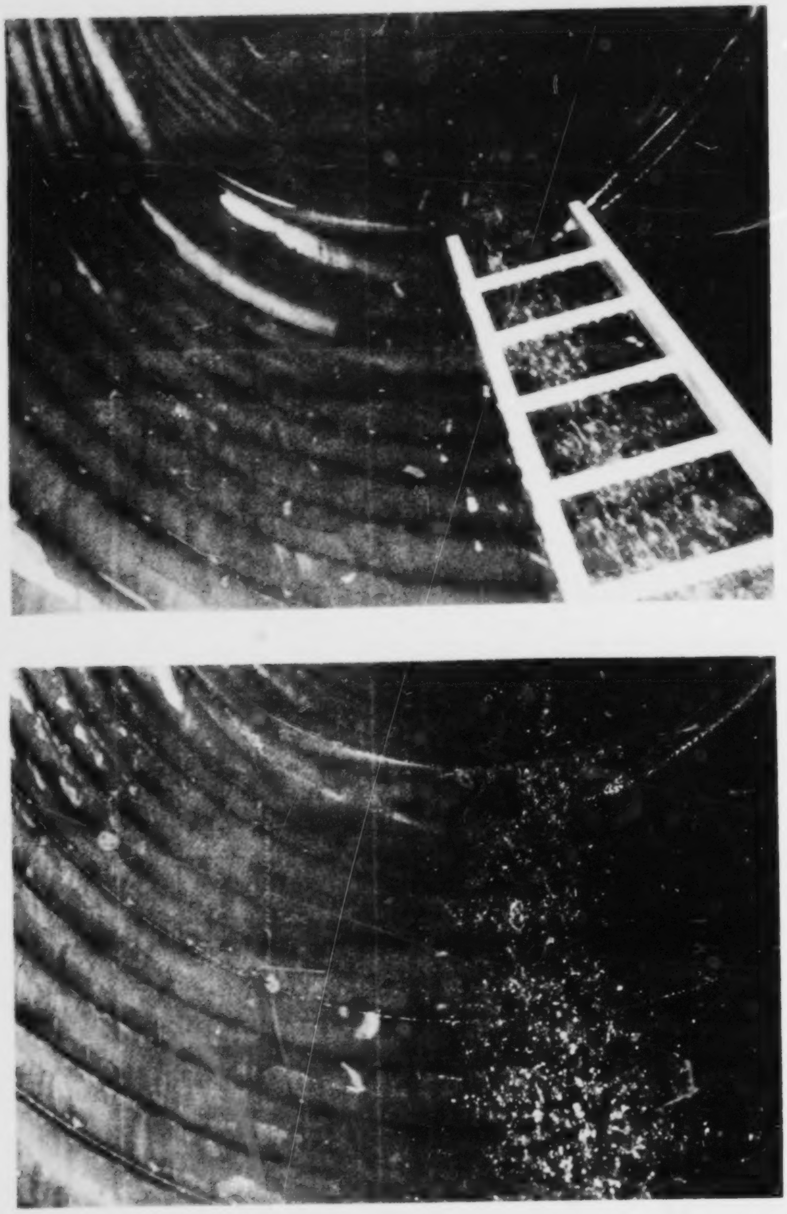


FIGURE I-2. COMPARATIVE PHOTOS OF STEEPLY DECLINED PORTION OF STANDARD 1" X 6" CORRUGATION 66" DIAMETER ON WRIGHT STREET LOOKING UP TOWARDS FIRST STREET FROM CANAL STREET

Upper Photo-Taken During 1973 Inspection Tour
Lower Photo-Taken During 1975 Inspection Tour

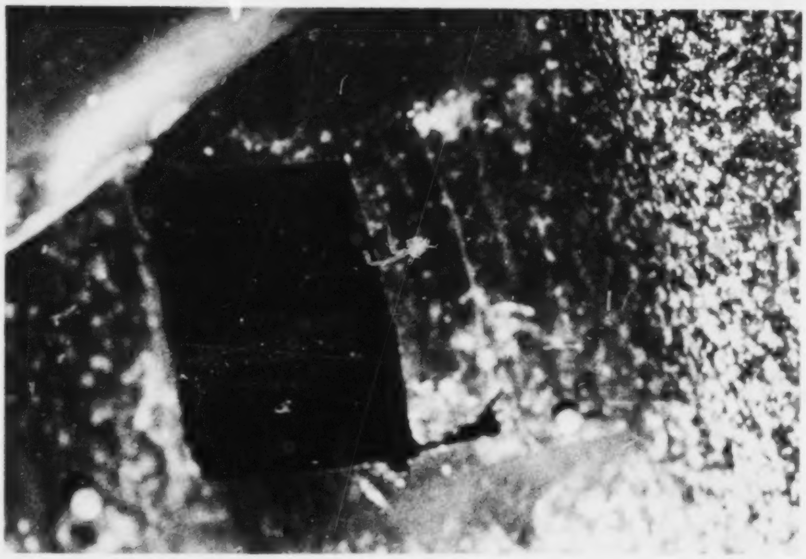


FIGURE I-3. TESTING 72" DIAMETER ALUMINUM PIPE THROUGH STEEL TUNNEL LINER

Photo of Rusted Steel Tunnel Liner Exposed to Moist Air Behind the Aluminum Pipe - Viewed Through Coupon Taken From 72" Standard 1 X 6 Corrugated Aluminum Pipe Under CRI & P Railroad

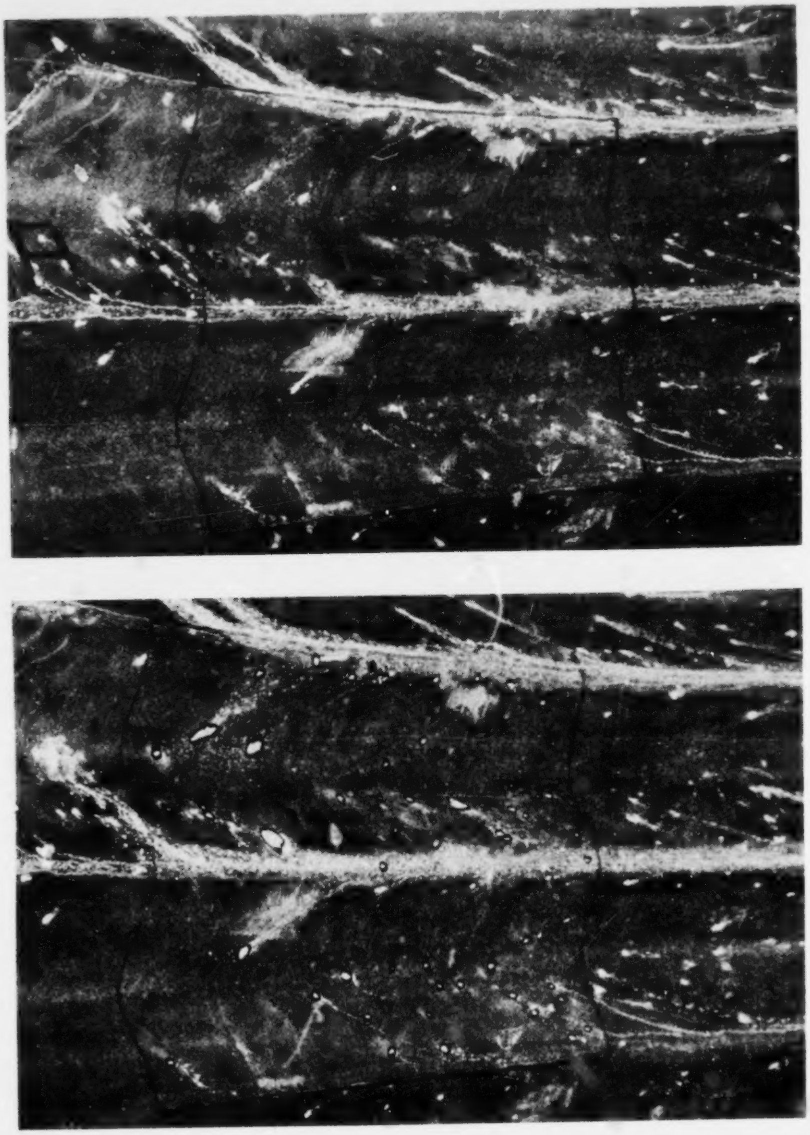
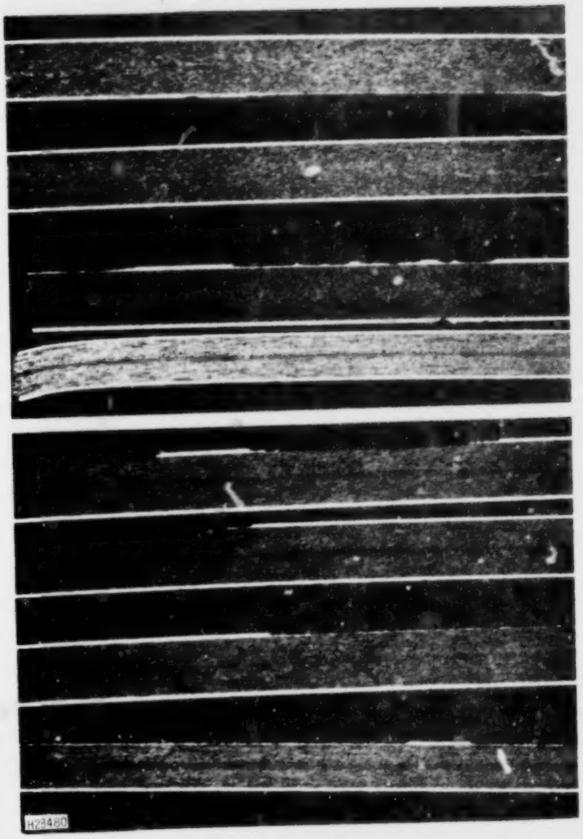


FIGURE I-4. CORROSIVE ATTACK ON STRUCTURAL PLATE ARCH

Upper Photo-Taken During 1974 Annual Inspection Tour.
Pit Blistering Corrosion and Pinhole
Perforations in 5052 Structural Plate Arch
(0.125 Inch)

Lower Photo-Comparative Photo Taken During 1975
Inspection Tour, Same Location as Upper
Photo



Sample No.	Pipe Size	Location
1.	72" diam. 1 x 6	125' S. of Canal St., in tunnel liner (invert)
2.	72" diam. 1 x 6	185' S. of Canal St.
3.	72" diam. 1 x 6	17' N. of Canal St.
7.	42" diam. 1 x 6	7.5' from elbow of the west side culvert, 3rd & Bucklin St.
8.	60" diam. 1 x 6	24' E. 6th & Bucklin St.
9.	60" diam. 1 x 6	40' S. 6th & Bucklin St.
10.	60" diam. 1 x 6	86' S. 6th & Bucklin St.
11.	42" diam. 1 x 6	65' S. 4th & Bucklin St.

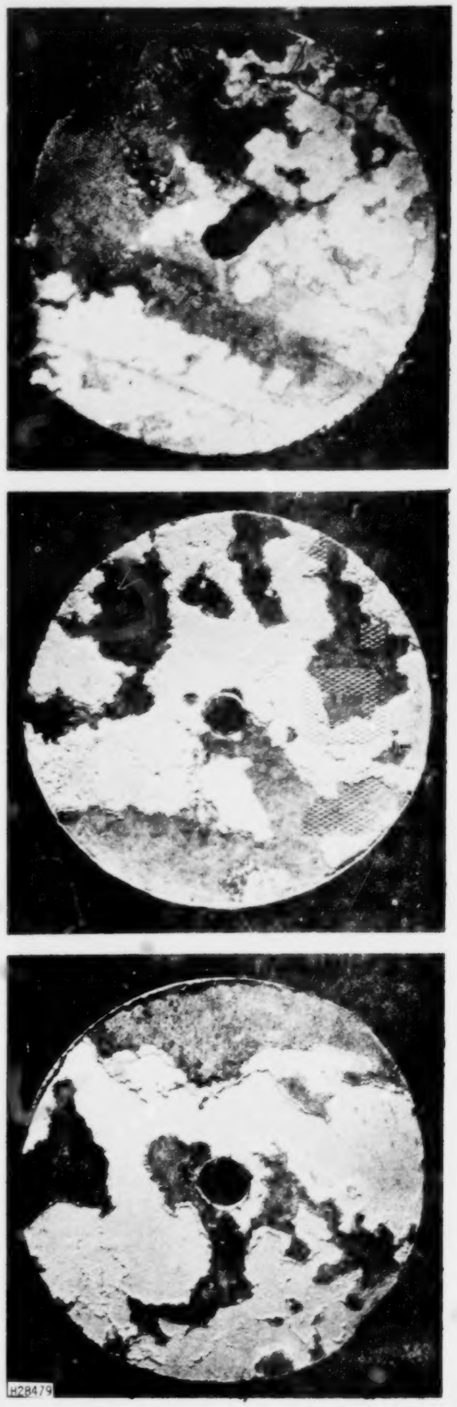
5X (etched HF/H_2SO_4)

FIGURE I-5. LASALLE, ILLINOIS ALCLAD 3004 STORM DRAIN PIPE - 3RD INSPECTION - 1975

PHOTO MICROGRAPHS

(Soil Side Up and Water Side Down in These Photos.)

The deepest appearing attack on the metal coupons was sectioned and mounted for a metallographic cross section. The corrosion is generally limited to the thin cladding layer.



SAMPLED IN 1973
(2 years' service)

SAMPLED IN 1974
(3 years' service)

SAMPLED IN 1975
(4 years' service)

Soil side of the pipe showing corrosion of the thin cladding has subsided after the initial attack. All three samples were removed from adjacent areas.

METAL TEST COUPONS
FIGURE I-6. ALCLAD 3004 60" DIAMETER - 1 X 6 PIPE
6th St. Between Bucklin and Wright, LaSalle, Illinois (Cleaned)

FIGURE I-7. TYPICAL LASALLE WASTE WATER ANALYSES

STORM DRAIN WATER ANALYSIS
BY KAISER ALUMINUM CENTER FOR TECHNOLOGY

Sample Taken and Analyzed as Part of Third Annual Inspection

ELEMENT	Quantity (ppm)
Chloride	220
Sulfate (SO_4)	550
Nitrate (NO_3)	16.3
Phosphate	1.7
Ca	360
Mg	75
Na	107
Fe	< 0.05
Pb	< 0.1
Cu	< 0.06
Ni	< 0.1
Total Solids	1,426
Total dissolved Solids	1,397
Suspended Solids	0.3

---

pH 7.5

Conductivity 1,786 μmho (560Ωcm resistivity)

FIGURE I-8. TYPICAL SOIL ANALYSIS

	QUANTITY (ppm)	
ELEMENT	#11 (NATIVE SOIL)	#8 (SANDY FLUID FILL)
Chloride	500	136
Sulfate (SO_4)	150	1,175
Nitrate (NO_3)	100	1.8
Phosphate	15	0.5
Suspended Solids	1.0	10.7
Ca	280*	400*
Mg	44*	92*
Na	175*	92*
pH	8.3	7.6
Conductivity	1,000μmho (1,000 Ωcm)	435μmho (2,300 Ωcm)

* determined by the atomic absorption method

In addition, a semi-quantitative spectrographic analysis of elements in the native soil was conducted (Location #11). The results are as follows:

(in % by weight)

Al	Si	Fe	Cu	Mn	Mg	Ti	V	Pb	Na	Ca	K
3.5	15.	3.8	0.01	0.10	2.0	0.23	0.01	0.001	0.42	5.0	1.0

Note: Numbers 11 and 8, Nature Soil and Sandy Fluid Fill as indicated above refer to samples extracted during 1975 inspection. See Figure I-1 for location.

The 1969 paper titled "Corrosion Evaluation of Aluminum Culvert Based on Field Performance" approached the question from two viewpoints with respect to service life, namely: (1) years to perforation and (2) metal loss to safety factor of one. Based on observation and analysis of nearly 1,000 sites over a broad spectrum of environments the predicted service lives based on the above conditions were 74 and 128 years respectively.

In view of the extensive data obtained from this project during the annual inspections since 1973 supported by numerous other investigations during the past seven years, a fresh approach to aluminum service life is in order. Of greatest single importance is a thorough appreciation of the difference in the corrosion mechanism between aluminum and steel. Prior to 1970, there appeared to be moderate support that the estimated years to perforation parameter represented the limit of aluminum pipe usefulness. Therefore, although not in total agreement with this approach, aluminum industry authors utilized this parameter in their 1969 paper. However, the aluminum industry now takes the position that any further reference to the "years to perforation" approach clearly exhibits complete ignorance and misunderstanding of the aluminum corrosion mechanism. This position can be supported by facts at hand.

After the galvanizing coating on steel culvert has been expended, the base metal undergoes a general progressive thinning process. When the first perforation is reached, the percent of remaining metal is quite small. Therefore, when evaluating steel pipe, occurrence of the first perforation is a good indication that the pipe is no longer adequate to support the surrounding soil medium. Conversely, although evidence of perforation of aluminum has been extremely limited, in each instance where such perforation has occurred in aluminum pipe, the pattern is typical random pin hole perforations. However, metal immediately adjacent to area under attack is completely intact. It is, thus, important to understand that total metal loss in these isolated incidences is extremely small. An excellent example of this may be found in the storm sewer system constructed as part of this project. During the first year after installation it was obvious from inspections that an aggressive element had leached through the pervious backfill material and attacked the exterior of the pipe in several isolated locations. During the second annual inspection (1974) an area of plate 18" x 36" which was thought to contain the most corrosion per unit area, was outlined and the perforations were circled and counted (see Figure I-4). The numbers and size of perforations have not increased during the past two years. However, it is interesting to use this example for calculation of metal loss and service life prediction. If we conservatively assume that corrosion will continue at the same rate, analysis is as follows:

Area outlined in August 1974 (Fig. I-4) -
18" x 36" = 648 in^2

Perforations counted - 60

Assume average diameter of perforation - 1/8"

The total area of perforation in four years of service

$$60 \frac{(\pi)(.125)^2}{4} = .74 \text{ in.}^2$$

Total metal loss = .11% or .03% per year assuming straight line corrosion attack, metal loss in 100 years will be 3%.

If we choose to use a far more conservative size of .25 inch perforation diameter - the analysis is as follows:
Total area of perforation in 4 years = $60 \frac{\pi(.25)^2}{4} = 2.95 \text{ in.}^2$

Total metal loss = .46% or .114% per year. Again, assuming a straight corrosion attack, metal loss in 100 years will be 11%.

The figure is still not enough to cause any great concern with regard to the structural integrity of the pipe.

The validity of this approach may be further substantiated by results of numerous metal coupon burials in Canadian, British and U.S. soils. These are reported by H.I. Godard's in his book titled "The Corrosion of Light Metals". The significance of Godard's figures is that while several alloys exhibited deep pitting in aggressive soils, the total metal loss in each instance was extremely small. Examples are as follows:

TABLE I-6. WEIGHT LOSS RELATIONSHIP TO SERVICE LIFE
CORRUGATED ALUMINUM PIPE

Alloy	Sheet Thickness	Years Exposure	Type of Soil	Max. Pit Depth in Mils	Weight Loss % of Origin
1100	.125	5 Years	Reclaimed Salt Marsh	66	1.0%
1100	.125	5 Years	London Clay	39	.2%
1100	.125	5 Years	Alluvial Tract	86	.1%
1100	.187	10 Years	London Clay	32	1.9%
1100	.187	10 Years	Reclaimed Salt Marsh	43	4.3%
1100	.187	10 Years	Sandy Peat	87	3.4%
3003	.187	10 Years	Sandy Peat	24	12.5%
3003	.064	5 Years	Stiff Clay	31	.1%
3003	.064	5 Years	Clay Silt	22	.2%
3003	.064	5 Years	Sandy	24	.1%
3003	.064	5 Years	Sandy	2	.4%
3003	.064	5 Years	Solodized Solonetz	0	.2%
3003	.064	5 Years	Angus Ridge Loam	35	.7%
3003	.064	5 Years	Solenetz Drag	7	.1%
3003	.064	5 Years	Rocky Clay	15	.2%

*The above should serve to establish the validity of using the weight loss approach in predicting long service life of aluminum pipe in various soil and water environments.

SECTION J

REFERENCES

1. American Society of Civil Engineers and WPCF, Design and Construction of Sanitary and Storm Sewers, WPCF Manual No. 10, 1970.

2. U.S. Department of Transportation, Federal Highway Administration, Bureau of Local Roads, Corrugated Metal Pipe Structural Design Criteria and Recommended Installation Practice, (1970).

3. State of New York Department of Transportation, Durability of Corrugated Metal Culverts, Physical Research Series, Research Report 66-5 (1967).

4. Lowe, T.A., Vaterlaus, R.H., Lindberg, R.I., and Lawrence, L.R., Corrosion Evaluation of Aluminum Culvert Based on Field Performance, (Highway Research Record 262) Highway Research Board, Washington, D.C. (1969).

5. Koepf, Almont H., The Mechanisms of Abrasion of Aluminum Alloy Culvert, Related Field Experiences, and a Method to Predict Culvert Performance, Highway Research Record 262, Highway Research Board, Washington, D.C. (1969).

6. Highway Research Board of the National Academy of Sciences-National Research Council, Field and Laboratory Testing of Aluminum, Highway Research Record No. 95, Publication 1311 (1965).

7. Corps of Engineers, U.S. Army Portland District, Friction Losses in Corrugated Metal Pipe, Civil Works Investigation 828 Report No. 40-1 (July, 1955).

8. Kaiser Aluminum & Chemical Sales, Inc., Corrugated Aluminum Pipe Storm Sewers, Technical Booklet.

9. Kaiser Aluminum & Chemical Sales, Inc., Aluminum Structural Plate, Technical Publication.

10. Silberman, Edward, Dahlin, Warren Q., Friction Factors for Helical Corrugated Aluminum Pipe, University of Minnesota St. Anthony Falls Hydraulic Laboratory, Project Report No. 112 (Dec., 1969).

11. Berg, Vernon E., P.E., Culvert Performance Evaluation, Materials Division Washington State Highway Commission Department of Highways, Research Project No. HPR-1-2 (April, 1965).

12. Raychem Corporation, Thermofit Heat-Shrinkable Couplers (Technical Bulletin-Heat Shrinkable Coupling Devices for Corrugated Aluminum Pipe) (April, 1969).

13. Environmental Protection Agency Water Quality Office, Heat Shrinkable Tubing as Sewer Pipe Joints, Water Pollution Control Research Series 11024 FLY, U.S. Government Printing Office (June, 1971).

SECTION K

APPENDIX A

UNIVERSITY OF MINNESOTA
ST. ANTHONY FALLS HYDRAULIC LABORATORY

Project Report No. 121

FURTHER STUDIES OF FRICTION FACTORS FOR CORRUGATED ALUMINUM PIPES FLOWING FULL

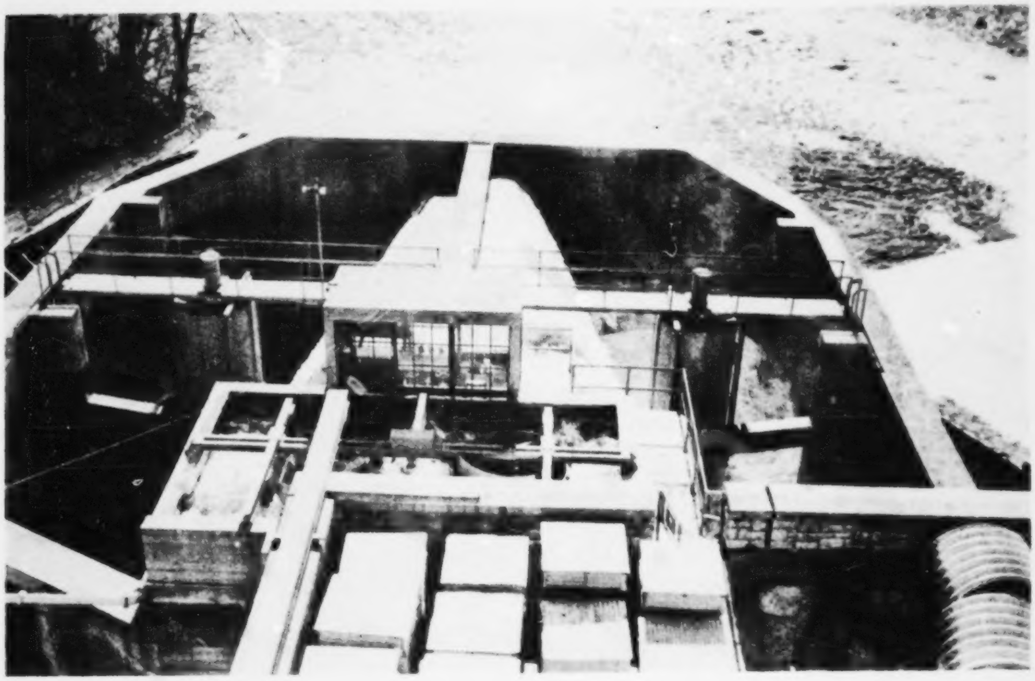
by
Edward Silberman
and
Warren Q. Dahlin

Prepared for

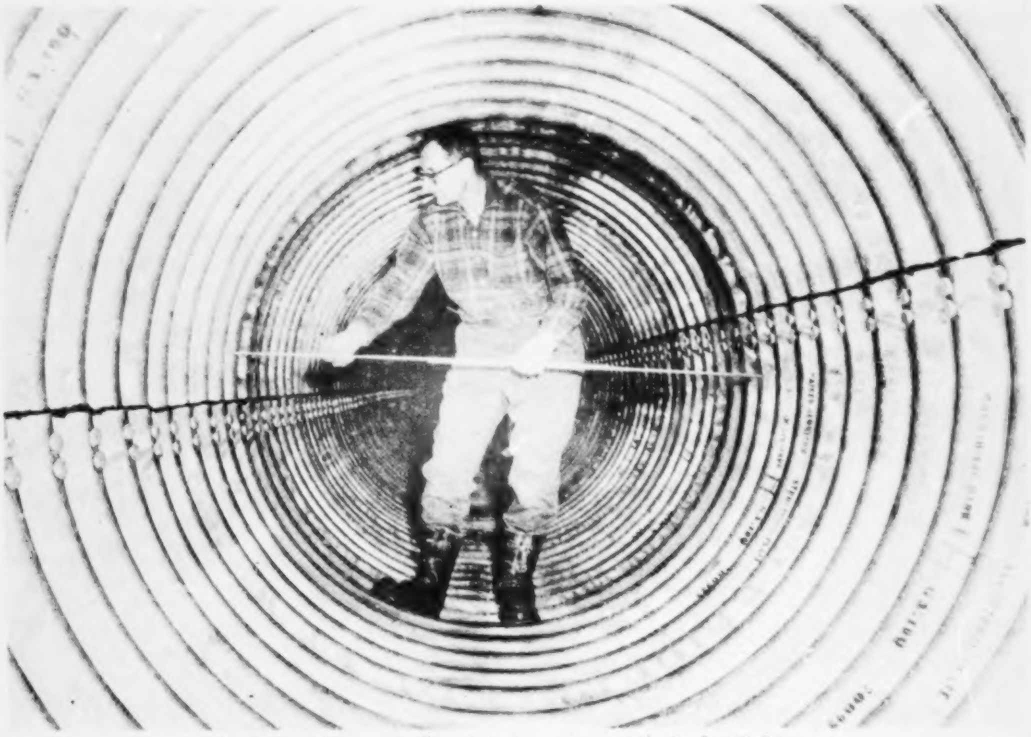
Department of Public Works
CITY OF LA SALLE, ILLINOIS

and

CHAMLIN AND ASSOCIATES, INC.
Peru, Illinois



Measuring a 300 cfs flow in the Volumetric Tanks



Inside View of the 66 in. Annular Bolted Pipe

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LIST OF SYMBOLS

A = area, ft^2

d = corrugation depth, ft

D = inside diameter of test pipe, ft

f = Darcy friction factor

g = acceleration due to gravity, ft/sec^2

h = head loss in pipe, ft

L = length of pipe, ft

n = Manning roughness coefficient

p = corrugation pitch, in.

P = perimeter, ft

Q = discharge, cfs

R_h = hydraulic radius = A/P, ft

R = radius, ft

Re = Reynolds number = $\overline{V}D/\nu$

Re_w = Wall Reynolds number = $Re \frac{d}{D} \sqrt{\frac{f}{8}}$

S = slope of hydraulic grade line = h/L

t = pipe wall thickness, in.

U = local velocity component parallel to axis of pipe = $V \cos \alpha$, fps

U_{max} = maximum local velocity component parallel to axis of pipe, fps

V = magnitude of local velocity, fps

$\overline{V}$ = average axial velocity = Q/A, fps

V_* = shear velocity = $\sqrt{\tau_o/\rho} = \overline{V}\sqrt{f/8}$, fps

Y = vertical distance from pipe invert to hydraulic grade line at exit, ft

y = vertical distance from wall of pipe, ft

α = angle between velocity vector and axis of pipe, deg

θ = helix angle of corrugation measured from axial direction, deg

ε = kinematic eddy viscosity, ft^2/sec

ν = kinematic viscosity, ft^2/sec

ρ = density, lb sec^2/ft^4

τ_o = shear stress, lb/ft^2

FUPTHER STUDIES OF FRICTION FACTORS FOR CORRUGATED ALUMINUM PIPES FLOWING FULL

I. PIPE CHARACTERISTICS

The St. Anthony Falls Hydraulic Laboratory was engaged by Chamlin and Associates, Inc., of Peru, Illinois, to determine the friction factors for fully developed flow in several sizes of annular and helical corrugated pipes flowing full and to make qualitative observations of the pipe joint characteristics. The pipes, which ranged in diameter from 12 to 66 inches, are being considered for use in a demonstration storm sewer project located in La Salle, Illinois, which is being supported in part by the Office of Water Quality of the U.S. Environmental Protection Agency. The pipe characteristics are given in Fig. 1.

Pipe for the tests was provided by two suppliers, Kaiser Aluminum and Chemical Sales, Inc., and the Reynolds Metals Company. Except for the 66 in. bolted pipe, the pipes were shipped to the laboratory in mostly 40 ft (a few 20 ft) lengths (Fig. 2) to provide a test pipe about 220 ft in length for the 66 in. and 48 in. sizes and about 100 ft in length for the 24 in. and 12 in. sizes. The 66 in. bolted pipe was shipped in 4.5 ft wide semi-circular pieces and assembled into a 220 ft length in the Laboratory's main test channel (Fig. 3). The pipes were inspected upon receipt to insure against leakage and to get accurate measurements for use in reducing test results. The seams of the factory-assembled pipes had been sealed with sealing compound during fabrication according to standard factory methods.

In some of the helical pipes, considerable sealant had been forced inside the pipe and would have affected the friction factor measurements. The 48 in. and 24 in. helical pipes were thoroughly scraped on the inside by Laboratory personnel. Since it was impossible for a man to enter the 12 in. pipe to scrape it, the first shipment of that size could not be used. It was replaced by a second shipment in which greater care had been taken during manufacture to prevent the sealant from getting inside the pipe.

The helical pipe seams did not leak during the experiments, but some leakage occurred from the annular riveted pipes and considerable leakage occurred from the bolted pipe. Leakage from the 48 in. annular riveted pipes, illustrated in Fig. 4, was easily stopped by application of silicone cement from outside the pipe. There was more leakage from the 66 in. annular riveted pipe, especially where the transverse and longitudinal seams met, but this was also sealed with silicone cement.

The greatest seam leakage problems occurred with the bolted pipe. The assembly materials included strips of 3M joint sealant tape which were applied over every row of bolt holes, both longitudinally and transversely. Notwithstanding this tape, leakage was severe until it was finally reduced to manageable proportions by inserting a black permagum sealer with a putty knife into all joints from the inside of the pipe. The sealed joints can be seen in the lower photograph of the frontispiece and in Fig. 5. Figure 5 also shows, incidentally, the roughness of the interior of the bolted pipe. It should be understood that this pipe, like all the pipes under test, was unsupported on the outside; with compacted earth fill around the pipe, the leakage would have been much less.

The inside pipe diameter is an important parameter in determining the friction factor, and it was measured carefully. Personnel entered all pipes 24 inches in diameter or larger and measured the actual inside diameters with two sliding bars equipped with verniers (frontispiece). The inside diameter of each pipe was measured every 2 ft (every 1-1/2 ft for the bolted pipe) through the test section in both vertical and horizontal directions. Corrugation depths were measured with a depth gage about every 4 ft, four readings being made at each section. For the 12 in. pipe, the outside diameter and corrugation depths were measured and the inside diameter computed. The average measured values of inside diameter, standard deviation, and corrugation depth are reported in Fig. 1 over the length of pipe used for determining hydraulic grade lines. The helix angle was also measured and is given in Fig. 1; it agreed closely with factory specifications.

II. TEST PREPARATIONS AND PROCEDURES

The pipes were installed in the laboratory flow system in two separate experimental set-ups as indicated in Figs. 6 and 7 and shown in the photographs of Figs. 8 through 10. Figure 6 shows the test arrangement for the 66 in. and 48 in. pipes in the 9-ft-wide-by-6-ft-deep-by-225-ft-long main test channel. Water from the Mississippi River enters the facility through a traveling mechanical screen, drops vertically down a dropshaft about 20 ft to the level of the main channel, and passes through a flow control baffle and under a sluice gate into the main channel. A head gate at the upstream end controls the inflow and a tailgate at the downstream end controls the tailwater level. The flow passes over the tailgate and out to the Laboratory's twin volumetric tanks (frontispiece). These tanks have a flow rate capacity up to 300 cfs and are calibrated to produce measurements which have an accuracy of 0.5 per cent.

Figure 7 shows the test arrangement for the 24 in. and 12 in. helical pipes, which is similar to the set-up used in earlier tests on helical pipe [1]*. Water for this facility is taken from the Mississippi River via a laboratory supply channel and drops about 18 ft through a 24 in. pipe. Water passes through a shut-off valve and three right-angled guide vane bends and enters the test pipe. A plate with a 12 in. hole was centered over the outlet of the 24 in. supply pipe to provide an entrance for the 12 in. pipe. At the downstream end a butterfly control valve of 24 in. or 12 in. size, as appropriate, was installed to control the discharge. The test pipe discharges into a channel from which the flow can be diverted to the laboratory volumetric tanks mentioned earlier or to the laboratory weighing tanks, which have a flow rate capacity up to 15 cfs with an accuracy of measurements of 0.1 per cent.

To measure the hydraulic grade lines, the downstream sections of all pipes were provided with 11 pairs of interconnected flush-mounted wall taps (Figs. 6, 7, and 11) spaced about 10 ft apart for the 66 in. and 48 in. pipes and 5 ft apart for the 24 in. and 12 in. pipes. This provided test section lengths of 100 ft and 50 ft, respectively, with the downstream tap 7.5 ft from the end of the pipe. These dimensions varied slightly depending on the type of pipe. The entry length was thus over 110 ft for the larger pipes and 40 ft for the smaller pipes. Hydraulic grade line measurements indicated that these were adequate to produce fully developed flow.

The flush-mounted wall taps were carefully located at the crests of the corrugations (as seen from inside) with a dial indicator. A 1/8 in. hole was drilled through the pipe wall and a rod was inserted in the hole. A mold was centered around the rod and plastic filler material was cast in the mold, and after it had set the rod was withdrawn. Pipe connectors were threaded into the holes to provide a means of connecting the piezometer lines to the pipe as shown in Fig. 11. The 11 piezometers were connected to a central manometer board. In the earlier study [1] a second piezometric system consisting of static tubes inserted 2-1/4 inches into the 24 in. pipe was used. The pressure drop recorded in the interior of the pipe by these tubes was nearly the same as the pressure drop measured by the wall taps. It was concluded in the earlier study that since the flow was fully developed, the wall taps would give reliable results; therefore, only the wall taps were used in the current study.

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*Numbers in brackets refer to references listed on page 134.

Since the main channel entrance is rectangular in cross-sectional shape, special transitions had to be made for the pipes. For the 48 in. pipes a bulkhead was installed under the sluice gate with an opening 48 inches high. A 20 ft section of 48 in. annular corrugated pipe was cemented into the bulkhead as shown in Fig. 12 and served as the inlet for all 48 in. pipes. For the 66 in. pipes, the end of a 20 ft section of 66 in. annular riveted pipe was compressed to 48 in., forced into the bulkhead, and cemented in place (Fig. 13). This provided a gradual transition from an elliptical inlet to the circular 66 in. pipe.

During the laying of the pipe, care was taken at the joints so that no unnecessary roughness would be introduced. The corrugations and crimps were carefully aligned and the joint taped with a fiber tape to prevent the intrusion of joint-sealing material. The joints were sealed using a heat-shrinkable coupler consisting of a thermoplastic sealant or asphalt-like material on a polyolefin sheet backing, applied with heat. While the coupler was still warm, a metal collar was placed over it to insure against leakage.

Without the metal collars, the heat-shrinkable couplings tended to start leaking during the tests. The 15 to 20 ft of head on the pipe, the cold water flowing through the pipe, vibrations, and the pipe's not being buried in the ground as it would be in a field installation to give it support probably contributed to this leakage problem at the joints. When a metal collar with corrugations to match the pipe corrugations was installed over the heat-shrinkable coupling, practically no leakage occurred. Non-corrugated collars were used on some pipe joints and were not as effective in preventing leakage.

In the main channel installations, the pipes were laid directly on the channel floor at an approximate slope of 0.00133 ft/ft. No attempts were made to adjust the slope of the large pipes, as the variation in pipe diameter was far greater than the irregularities in the channel floor. The pipe was aligned and horizontal braces to the channel sides were placed every 20 ft; in addition, several cables were placed over the pipe and anchored to the floor. A watertight bulkhead was installed near the downstream ends of the pipes. Before tests were run, the joints, taps, and alignment were checked inside the pipe. The 24 in. and 12 in. pipes were laid on wooden sleepers placed about every 5 ft with horizontal side braces placed about every 10 ft. These smaller pipes were set to a grade of 0.002 ft/ft with the pipe filled with water. Levels were recorded for all pipes, both filled with water and empty, and the measurements showed that the pipes flattened out slightly when filled (on the order of 1/64 in. for the 12 in. pipe and 1-1/4 in. for the 66 in. riveted pipe).

Provisions were also made for installation of a 3/8-inch-diameter pitot cylinder in the 24 in. and 12 in. pipes (Fig. 7) to measure velocity direction and magnitude [2]. Glands similar to those used for pressure taps were cast on the top and bottom of the pipe through which the pitot cylinder was inserted to measure the total head along a vertical diameter. In the same section, on the side of the pipe, a special gland was cast for the insertion of a static tube to measure the static pressure for use with the total head readings from the pitot cylinder.

A test run involved establishing a given discharge through the test pipe, measuring the discharge and water temperature, and reading the wall tap pressures on the manometer board. The discharge was regulated for the smaller pipes by the downstream valve; in the main channel the flow was regulated using the tailgate and a head loss baffle in the channel entrance structure. All discharges from the main channel and those above 15 cfs for the smaller pipes were measured in the volumetric tanks; flows up to 15 cfs were measured in the weighing tanks. The usual procedure was to make two discharge measurements during the reading of the manometer board. As some manometer tubes fluctuated considerably for some runs, each tube was observed for a period of time and a visual average was determined. It took from 30 to 45 minutes to make a run in the smaller pipes and about twice as long in the larger pipes. A number of runs were made for each pipe to establish the friction-factor-versus-Reynolds-number curve. Most runs for the 12 and 24 in. pipes were made with the downstream valve in place. For the larger pipes, the tailwater was raised to the top of the pipe for most tests. To obtain maximum discharge, however, several runs for each pipe were made with the downstream valve removed or with no tailwater. These latter results were also used to determine the tailwater depth at exit. In addition, velocity profiles were measured for one discharge in the 24 in. pipe and one in the 12 in. pipe.

The remainder of the body of this paper is devoted to a report on the friction factor measurements. The measurements of tailwater depth at exit are discussed in Appendix A and the velocity measurements in Appendix B.

III. FRICTION FACTORS

The Darcy friction factor f, the Manning roughness coefficient n, and the Reynolds number Re were computed from the test data for each run. The Darcy friction factor f was determined from

$$f = \frac{2gDS}{\overline{V}^2} \tag{1}$$

with $S = h/L$ where h is the head loss over the length of pipe L, both in feet, and g is the acceleration of gravity in ft/sec^2. The Manning roughness coefficient n was determined from

$$\overline{V} = \frac{1.486}{n} R_h^{2/3} S^{1/2} \quad \text{or} \quad n = \frac{1.486\ R_h^{2/3}\ S^{1/2}}{\overline{V}} \tag{2}$$

where R_h is the hydraulic radius of the cross section, area divided by the wetted perimeter, both based on measured inside diameter. The Reynolds number Re was computed from

$$Re = \frac{\overline{V}D}{\nu} \tag{3}$$

In all the equations the mean velocity $\overline{V}$ was computed from $\overline{V} = Q/A$, where Q is the measured discharge and A is the area based on the average measured inside diameter D. Kinematic viscosity ν was obtained from standard tables using the measured water temperature.

Typical hydraulic grade lines observed on the manometer board for the seven pipes tested are plotted in Figs. 14 through 20. For convenience, the hydraulic grade lines for each pipe are shown together on one plot and to the same vertical scale. Individual plots were made for determining the slope S from the hydraulic grade lines, and for lower discharges the vertical scale was expanded to obtain more accuracy in the results.

Most of the grade lines plotted as straight lines, indicating that the flow was fully developed through the test section, although deviations occurred for some pipes. Particularly noticeable are the variations for the 48 in. helical pipe with 2 in. by 1/2 in. corrugations (Fig. 17) from stations 120 through 170 (taps 1 through 7). Investigation showed an almost perfect correlation between these pressure variations and variations in the measured inside diameter of the pipe. The last 40 ft of the pipe had a fairly uniform inside diameter, the average being 48.47 in. with a standard deviation of 0.2042 in. based on measurements every 2 ft; this is the length for which the data are shown in Fig. 1 and on which the slope measurement was based. Measurements at taps 5 (station 151.6 ft) and 6 (station 161.5 ft) indicated the inside diameters to be 50.46 in. and 49.82 in., respectively. The inside diameter at tap 3 (station 131.4 ft) was found to be 48.3 in. The standard deviation from taps 1 through 11 was 0.7655 in., and this is why the hydraulic grade line was not drawn through all points. When the individual pressure readings were corrected for the change in velocity head caused by the variations in diameter, the points were found to plot considerably closer to the grade lines shown in Fig. 17.

Some variations in hydraulic grade lines are thus attributed to variations in the inside diameter of the pipe; another factor which could have affected the readings is the closeness to one of the wall taps of a helical lock seam on the helical pipe or an overlapping seam on the annular pipe.

Summaries of the friction measurements for the seven pipes tested are presented in Tables I through VII. The variations of Darcy friction factor f with Reynolds number Re are shown in Fig. 21 for the 66 in. pipes, Fig. 22 for the 48 in. pipes, and Fig. 23 for the 24 in. and 12 in. pipes. The variations of the Manning roughness coefficient n with Reynolds number are shown in Fig. 24 for the 66 in. pipes, Fig. 25 for the 48 in. pipes, and Fig. 26 for the 24 in. and 12 in. pipes. The data appear to plot in a reasonably consistent manner.

For the annular pipe, the wall Reynolds number defined by

$$Re_w = \frac{dV_*}{\nu} = Re \frac{d}{D} \sqrt{\frac{f}{8}} \qquad (4)$$

where d is the corrugation depth and V_* the friction velocity, was also computed. Values of f versus Re_w are plotted in Fig. 27.

There is some scatter in the plots of friction factor, especially for the larger pipe sizes. Discharge remained quite constant during each run and was measured quite accurately. Since diameter was fixed for each pipe size, whether or not it was measured correctly, the probable cause of the scatter was the difficulty in reading the fluctuating manometer tubes. The fluctuations occurred as rather short-term pulses and longer-term surges, neither of which could be damped out completely. The difficulty in reading increased at lower Reynolds numbers because of the smaller head loss.

For the 66 in. pipes, friction factors are essentially constant above a Reynolds number of about 1.5 million. The average f values from Fig. 21 are 0.137 for the annular bolted pipe with 9 in. by 2-1/2 in. corrugations and 0.0617 for the annular riveted pipe with 6 in. by 1 in. corrugations. The corresponding n values are 0.0360 and 0.0242, respectively. Below a Reynolds number of about 1.5 million, the friction factors for the bolted pipe increase with Reynolds number, while for the riveted pipe they decrease.

For the 48 in. annular pipes, friction factor is approximately constant above a Reynolds number of about 2 million. For the helical pipes, the constant regime may extend through all of the data. The average f values from Fig. 22 are 0.0684 for the annular riveted pipe with 6 in. by 1 in. corrugations, 0.0533 for the helical pipe with 2 in. by 1/2 in. corrugations, and 0.0484 for the helical pipe with 2-2/3 in. by 1/2 in. corrugations. The corresponding n values from Fig. 25 are 0.0242, 0.0214, and 0.0204, respectively. For the annular pipe below a Reynolds number of about 2 million, the friction factors appear to be falling with increasing Reynolds number as was the case with the 66 in. annular riveted pipe.

For the 24 in. helical pipe with 2-2/3 by 1/2 in. corrugations, friction factors are constant above a Reynolds number of about 250,000. In this region the average f is about 0.0422 and n about 0.0169. For the 12 in. helical pipe with 2-2/3 by 1/2 in. corrugations, the constant friction factor regime lies above a Reynolds number of about 600,000 with f about 0.0229 and n about 0.0111. In both cases, friction factor decreases as Reynolds number increases.

The friction factor data for all these tests at large Reynolds numbers have been tabulated in Table VIIIa.

IV. DISCUSSION OF FRICTION FACTOR RESULTS

All the present data, as well as the previous data obtained at the St. Anthony Falls Hydraulic Laboratory for helical pipes [1], show a region of more or less constant friction factor at large Reynolds numbers. This is true for both helical and annular corrugated pipe, as can be seen in Figs. 21 through 27 and in Figs. 10 and 11 of the earlier report. The region of constant friction factor can be termed the region of fully rough flow in accordance with the usual practice.

The measured friction factors from the present tests in the fully rough flow regime are summarized in Table VIIIa along with other information. They are plotted in Fig. 28 as log f versus log pipe diameter and in Fig. 29 as n versus log pipe diameter. The points can be identified by the symbols shown in the table. Comparable data from the earlier work at the St. Anthony Falls Hydraulic Laboratory and from the work of others are tabulated in Table VIIIb and are also plotted in Figs. 28 and 29.

Referring first to Figs. 21 through 27, the helical pipe data obtained by others [3,4] are in general agreement with the present data as regards trends of friction factor versus Reynolds number. The annular pipe data obtained by others [6,7], and even those obtained earlier at the St. Anthony Falls Hydraulic Laboratory [5], show some notable differences in trends from those of the present data. For example, all the previous data for annular pipe show a rising friction factor characteristic with increasing Reynolds number at smaller Reynolds numbers, whereas the present data for riveted annular pipe show a falling characteristic (Figs. 21, 22, 24, and 25). Perhaps the opposite trends can be explained by the relative spacing of the corrugations, the present riveted pipe corrugations being 6 by 1 in. whereas all the previous tests on annular pipe were for 2-2/3 by 1/2 in. corrugations as shown in Table VIII. The present bolted pipe results for shorter relative pitch do show a rising friction factor with increasing Reynolds number (Figs. 21 and 24). Another difference occurs for the Webster and Metcalf data [6]. Apparently these data fail to show a region of constant friction factor (fully rough flow) at large Reynolds numbers, but rather seem to peak and fall back again; this trend is not confirmed with certainty by any other data. One explanation given for the latter phenomenon has been that at higher Reynolds numbers the waviness or corrugation spacing becomes more important than the depth of the corrugations. Nevertheless, on the present riveted annular pipes, pitch over corrugation depth and pitch over pipe diameter are both larger than for the Webster and Metcalf tests, while for the bolted pipe they are both less and the tests show no such peaking. For further analysis, the annular pipe friction factors given in Table VIIIb and plotted in Figs. 28 and 29 have been taken as the peak values at large Reynolds number.

In Fig. 28, all data for riveted pipe with annular corrugations fall approximately on a straight line as is suggested by Neill [7] independently of relative roughness or relative pitch (if the 7 ft diameter pipe data of Webster and Metcalf are not weighted too heavily). The equation for this line can be written

$$f = 0.122\ D^{-0.41} \qquad (5)$$

where D is the pipe diameter in feet. The line is plotted on the figure. The corresponding equation for n,

$$n = 0.0257\ D^{-0.042} \qquad (6)$$

has been plotted in Fig. 29; it is not quite a straight line there because of the semi-logarithmic plotting. It is apparent that for annular riveted pipe, n decreases very slowly with diameter at large Reynolds numbers.

The annular aluminum pipe data fall in nicely with the annular steel pipe data taken by others even though the relative roughness as shown in Table VIII is greater for the aluminum pipe than for the steel pipe at any given diameter. The explanation for this may lie in the greater pitch of the aluminum pipe as just discussed. It is likely that a combination of relative roughness and waviness determines friction factor as a function of diameter for fully rough flow in annular corrugated pipe.

The plotted points for bolted steel and aluminum pipe seem to substantiate this argument. Both plotted points for bolted pipe represent pipes with greater relative roughness and more abrupt waviness than the riveted pipes, and the friction factors are correspondingly larger. The aluminum bolted pipe has greater relative roughness, but less abrupt waviness than the steel pipe, and this may explain why the two data points fall close to each other. Much more work is necessary to determine the relative contributions of roughness and waviness to friction factors for annular corrugated pipe. (Some of the increase in friction factor for the bolted pipes over that of the riveted pipes is also due to bolt heads in the flow and to the rougher joints associated with field assembly, as shown in Fig. 5. Computations for the bolt head contributions are given by Bossy in Appendix A of Ref. [8].)

For the helical pipe it appears from Figs. 28 and 29 that friction factor increases with diameter for pipe of a given manufacture (i.e., fixed width of sheet from which the pipe is rolled). However, it was observed in an earlier paper by one of the authors [9] that if helical corrugated pipe could be manufactured with helix angle kept constant while the diameter (width of sheet) was increased, the friction factor would actually decrease as diameter increased, much as in the case of annular pipe. To explore this hypothesis further, it was proposed to draw lines parallel to the annular pipe data line in Fig. 28 representing the various helix angles. To this end the f values in Table VIII have been converted to $fD^{0.41}/0.122$ and plotted versus helix angle in Fig. 30. The straight line in Fig. 30 fits most of the data well and tends to substantiate the hypothesis. It has the equation

$$f = 0.945 \times 10^{-8} \frac{\theta^{3.64}}{D^{0.41}} \tag{7}$$

where θ, the helix angle, is in degrees and D, the pipe diameter, is in feet. Straight lines representing this equation have been drawn in Fig. 28 for 60, 70, and 80 degree helix angles. These are of the form

$$f = C\, D^{-0.41} \tag{8}$$

where C has the values 0.282, 0.491, and 0.805 for 60, 70, and 80 degree helix angles, respectively. Figure 28 now replaces Fig. 1 of Ref. [9]. The corresponding equation for n is

$$n = 7.13 \times 10^{-6} \frac{\theta^{1.82}}{D^{0.042}} \tag{9}$$

and if this is written in the form

$$n = C_1 \, D^{-0.042} \tag{10}$$

C_1 has the values 0.0122, 0.0160, and 0.0206 for 60, 70, and 80 degree helix angles, respectively. Corresponding lines have been drawn in Fig. 29. Again, the lines are not quite straight because this is a semi-logarithmic plot.

It seems that if helical corrugated pipe of, say, 70 degree helix angle could be fabricated at larger diameters, there would be every reason to expect n values near 0.015 for 3 and 4 ft diameter pipes. A sheet width of about 40 in. would be required for a 3 ft pipe.

In analyzing the effect of helix angle in Fig. 30, no attention has been given to relative roughness or waviness. In fact, inspection of Table VIII shows that relative roughness generally increases with decreasing helix angle and decreasing friction factor, which is the opposite trend from that found in annular pipe. Waviness varies throughout the data. In order to determine whether there is a consistent effect of relative roughness on friction factor for helical pipes, a plot of

$$\frac{f \, D^{0.41}}{0.945 \, \theta^{3.64}} \times 10^8$$

versus d/D was made (Fig. 31). This form of plotting removes the influence of helix angle. The plot shows that there may be a trend for increasing friction factor with increasing relative roughness which has previously been masked by the overriding effect of helix angle. Some of the scatter in Fig. 30 may be due to this effect. No trend attributable to waviness could be detected on a similar graph.

The empirical formulas quoted for f and n as functions of θ should not be extended to smaller helix angles. The data point for the 52-1/2 degree helix angle in Fig. 30 already looks suspicious, although its deviation from the empirical correlation line may be due to relative roughness. The problem is that the mechanism by which spiral flow reduces friction is not known, and until it is, the empirical formulas quoted can be used only within the limits in which they appear to fit the data. It was suggested in Ref. [9] that flow rotation imparted by the spiral corrugations is responsible for friction decrease through reduction in turbulence. Even if this suggestion is valid, it is still necessary to connect the helix angle with the turbulent mixing parameter in the interior of the pipe, and this cannot be done at present.

V. CONCLUSIONS

The experiments described in this report have been conducted using corrugated aluminum pipes flowing full. The measurements were made following an entry region of 20 or more pipe diameters, and although this distance appears to be sufficient, it is not known whether this is a minimum distance for fully developed flow. Measurements were made under laboratory conditions with pipe carefully aligned and joints carefully made so as to avoid introducing additional roughness. The water used in the tests carried a light load of sand, mostly as suspended load, from the Mississippi River. No significant amount of sand was found in the pipes after the flow was shut down; it is not believed that the sand affected the results.

Under these conditions, the following statements can be made regarding friction factors:

1. Aluminum annular riveted pipes with 6 in. by 1 in. corrugations have the same friction factors for fully rough flow as do steel riveted pipes with 2-2/3 by 1/2 in. corrugations. Empirical formulas including both are

   $$f = 0.122\ D^{-0.41}$$

   and

   $$n = 0.0257\ D^{-0.042}$$

   where D is the inside diameter measured in feet. Field assembled and bolted pipes have materially greater friction factors because of both the larger relative depth of corrugations and the presence of bolt heads and rougher joints within the pipes.

2. Helical pipe has lesser friction factors than similar annular pipe of the same diameter; the smaller the helix angle, the less the friction factor. Empirical formulas including both annular and helical pipes of both aluminum and steel are

$$f = 0.945 \times 10^{-8} \frac{\theta^{3.64}}{D^{0.41}}$$

and

$$n = 0.713 \times 10^{-6} \frac{\theta^{1.82}}{D^{0.042}}$$

where θ is the helix angle (measured from the pipe axis) in degrees and D is the inside diameter measured in feet. These formulas are limited to the range of the data available, $52\text{-}1/2 \leq \theta \leq 90$. There appears to be little effect of relative roughness on helical pipe friction factors.

3. The thermoplastic sealant provided for the aluminum pipe tests makes a very effective field seal at the pipe joints. However, in the laboratory tests without earth backfill around the pipes, it was found necessary to reinforce the joint seals with corrugated metal bands to prevent the seals from opening due to pressure and vibration. The bands materially increased the rigidity of the pipe line. (Plain metal bands did not protect the seal as well as corrugated bands.) Using corrugated metal bands it was also possible to seal the joints with bands of rubber gasket material placed cold, but several trials were necessary at each joint before a tight seal could be made.

4. The factory-assembled pipes, especially the helical pipes which contained sealant in the spiral joints, were reasonably tight against leakage even without backfill. The field assembled, bolted pipe leaked badly even though sealer strips were used along the bolt rows.

5. In factory assembled pipe, care should be taken to avoid unnecessary joint roughness. Extruding joint sealant from spiral joints on helical pipe, which can introduce roughness, should be avoided.

LIST OF REFERENCES

[1] Silberman, E. and Dahlin, W. Q., Friction Factors for Helical Corrugated Aluminum Pipe, Project Report No. 112, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, December 1969.

[2] Silberman, E., The Pitot Cylinder, Circular No. 2, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, October 1947.

[3] Rice, C. E., Friction Factors for Helical Corrugated Pipe, ARS 41-119, Agricultural Research Service, U.S. Department of Agriculture, February 1966.

[4] Chamberlain, A. R., Discussion of [6], Journal of the Hydraulics Division, ASCE, Vol. 86, No. HY3, Proc. Paper 2148, March 1960, pp. 67-74.

[5] Straub, L. G. and Morris, H. M., Hydraulic Tests on Corrugated Metal Culvert Pipes, Technical Paper No. 5-B, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, 1950.

[6] Webster, M. J. and Metcalf, L. R., "Friction Factors in Corrugated Metal Pipes," Journal of the Hydraulics Division, ASCE, Vol. 85, No. HY9, September 1959, pp. 35-67.

[7] Neill, C. R., "Hydraulic Roughness of Corrugated Pipes," Journal of the Hydraulics Division, ASCE, Vol. 88, No. HY3, May 1962, pp. 23-44, and Closure of Discussion, Vol. 89, No. HY4, July 1963, pp. 205-208.

[8] Grace, J. L., Jr., Resistance Coefficients for Structural Plate Corrugated Pipe, Technical Report No. 2-715, U.S. Army Engineer Waterways Experiment Station, February 1966.

[9] Silberman, E., "Effect of Helix Angle on Flow in Corrugated Pipes," Journal of the Hydraulics Division, ASCE, Vol. 96, No. HY11, November 1970, pp. 2253-2263.

TABLE I. SUMMARY OF FRICTION MEASUREMENTS FOR 66-INCH ANNULAR RIVETED PIPE WITH 6-INCH BY 1-INCH CORRUGATIONS

Average measured diameter = 5.4517 ft

Q cfs	$\bar{V}$ fps	S per cent	Water Temp. Deg. F	ν ft^2/sec x 10^5	Re x 10^{-6}	Darcy f	Manning n
302.81*	12.972	2.9537	33.0	1.895	3.7320	0.0616	0.0242
299.81	12.844	2.9537	33.0	1.895	3.6950	0.0628	0.0244
285.84	12.245	2.7152	34.0	1.859	3.5911	0.0635	0.0246
282.78*	12.114	2.4546	33.0	1.895	3.4852	0.0587	0.0236
279.82	11.988	2.5883	33.0	1.895	3.4487	0.0632	0.0245
277.94*	11.907	2.5248	33.0	1.895	3.4255	0.0625	0.0244
253.33	10.853	2.1146	33.0	1.895	3.1222	0.0630	0.0245
253.31*	10.852	1.9032	33.0	1.895	3.1220	0.0567	0.0232
249.92*	10.707	2.0191	33.0	1.895	3.0802	0.0618	0.0242
246.90	10.577	1.9709	33.0	1.895	3.0430	0.0618	0.0242
246.45*	10.558	1.9454	33.0	1.895	3.0374	0.0612	0.0241
246.04*	10.540	2.0115	33.0	1.895	3.0323	0.0635	0.0246
245.84*	10.532	1.7678	33.0	1.895	3.0299	0.0559	0.0231
223.08	9.557	1.5690	34.0	1.859	2.8026	0.0603	0.0239
213.16	9.132	1.4396	34.0	1.859	2.6780	0.0606	0.0240
213.06	9.128	1.3745	33.0	1.895	2.6259	0.0579	0.0235
212.75*	9.114	1.3728	33.0	1.895	2.6221	0.0580	0.0235
211.80	9.074	1.3787	33.0	1.895	2.6104	0.0588	0.0236
201.32	8.625	1.2375	33.0	1.895	2.4812	0.0584	0.0236
179.64	7.696	1.0675	34.0	1.859	2.2569	0.0632	0.0245
165.99	7.111	0.8899	34.0	1.859	2.0854	0.0617	0.0242
154.66	6.626	0.7884	34.0	1.859	1.9430	0.0630	0.0245
138.64	5.939	0.6555	33.0	1.895	1.7087	0.0652	0.0249
124.06	5.315	0.5050	33.0	1.895	1.5290	0.0627	0.0244
109.31	4.683	0.4238	33.0	1.895	1.3472	0.0678	0.0254
93.52	4.006	0.3324	33.0	1.895	1.1526	0.0726	0.0263
77.40	3.316	0.2415	33.0	1.895	0.9539	0.0770	0.0271
58.23	2.495	0.1269	33.0	1.895	0.7177	0.0715	0.0261
39.70	1.701	0.0846	33.0	1.895	0.4893	0.1025	0.0312
22.96	0.984	0.0212	33.0	1.895	0.2830	0.0769	0.0270

*No tailwater

TABLE II. SUMMARY OF FRICTION MEASUREMENTS FOR 66-INCH ANNULAR BOLTED PIPE WITH 9-INCH BY 2-1/2-INCH CORRUGATIONS

Average measured diameter = 5.38083 ft

Q cfs	$\overline{V}$ fps	S per cent	Water Temp. Deg. F	ν ft^2/sec x 10^5	Re x 10^{-6}	Darcy f	Manning n
248.64	10.934	4.8451	34.0	1.859	3.1648	0.1403	0.0364
246.09*	10.822	4.5901	34.0	1.859	3.1324	0.1357	0.0358
237.68	10.452	4.3749	34.0	1.859	3.0254	0.1387	0.0362
230.14	10.121	4.0084	34.0	1.859	2.9293	0.1355	0.0358
226.49	9.960	4.0243	34.0	1.859	2.8829	0.1405	0.0365
219.66*	9.660	3.7852	34.0	1.859	2.7960	0.1405	0.0365
216.95*	9.540	3.5860	34.0	1.859	2.7614	0.1364	0.0359
215.99	9.498	3.2114	34.0	1.859	2.7492	0.1232	0.0342
210.31	9.248	3.4027	34.0	1.859	2.6769	0.1377	0.0361
208.49*	9.168	3.4067	34.0	1.859	2.6538	0.1403	0.0364
198.94*	8.748	2.9485	34.0	1.859	2.5323	0.1334	0.0355
187.50	8.245	2.7413	34.0	1.859	2.3866	0.1396	0.0364
180.50*	7.938	2.4624	34.0	1.859	2.2975	0.1353	0.0358
175.79	7.730	2.3349	34.0	1.859	2.2376	0.1353	0.0358
170.58	7.501	2.2154	34.0	1.859	2.1713	0.1363	0.0359
150.96	6.639	1.7332	34.0	1.859	1.9215	0.1362	0.0359
141.91	6.241	1.5436	34.0	1.859	1.8063	0.1372	0.0360
131.88	5.800	1.2846	34.0	1.859	1.6787	0.1322	0.0354
119.61	5.260	1.0543	34.0	1.859	1.5224	0.1319	0.0354
106.72	4.693	0.8296	34.0	1.859	1.3584	0.1304	0.0351
89.84	3.951	0.5778	34.0	1.859	1.1436	0.1282	0.0348
75.18	3.306	0.3985	34.0	1.859	0.9569	0.1262	0.0346
58.55	2.575	0.2207	34.0	1.859	0.7453	0.1153	0.0330
39.72	1.747	0.0797	34.0	1.859	0.5056	0.0904	0.0292
23.27	1.023	0.0281	34.0	1.859	0.2962	0.0930	0.0297

*No tailwater

TABLE III. SUMMARY OF FRICTION MEASUREMENTS FOR 48-INCH ANNULAR RIVETED PIPE WITH 6-INCH BY 1-INCH CORRUGATIONS

Average measured diameter = 3.9683 ft

Q cfs	$\bar{V}$ fps	S per cent	Water Temp. Deg. F	ν ft^2/sec x 10^5	Re x 10^{-6}	Darcy f	Manning n
181.73*	14.694	5.6809	56.0	1.289	4.5235	0.0672	0.0240
175.22	14.167	5.2446	58.0	1.253	4.4868	0.0667	0.0239
175.05	14.153	5.3302	58.0	1.253	4.4825	0.0680	0.0241
164.62	13.310	4.7484	58.0	1.253	4.2154	0.0684	0.0242
164.15	13.272	4.6714	58.0	1.253	4.2033	0.0677	0.0241
157.43	12.729	4.3634	59.0	1.235	4.0900	0.0688	0.0243
147.15*	11.898	3.7987	56.0	1.289	3.6628	0.0685	0.0242
147.14*	11.897	3.9958	56.0	1.289	3.6625	0.0721	0.0248
136.28	11.019	3.2426	62.0	1.183	3.6962	0.0682	0.0242
125.62	10.157	2.8148	60.0	1.217	3.3119	0.0697	0.0244
124.70	10.082	2.7122	60.0	1.217	3.2876	0.0681	0.0241
105.49	8.529	1.9422	60.0	1.217	2.7812	0.0682	0.0242
91.37*	7.388	1.4160	56.0	1.289	2.2743	0.0662	0.0238
91.34	7.385	1.4930	60.0	1.217	2.4081	0.0699	0.0245
86.32	6.979	1.2492	64.0	1.151	2.4062	0.0655	0.0237
75.37	6.094	1.0241	59.0	1.235	1.9581	0.0704	0.0246
59.04	4.774	0.6306	59.0	1.235	1.5339	0.0707	0.0246
58.29	4.713	0.6194	63.0	1.167	1.6026	0.0712	0.0247
55.47	4.485	0.5758	64.0	1.151	1.5463	0.0731	0.0250
39.10	3.161	0.3011	56.0	1.289	0.9733	0.0769	0.0257
21.71	1.755	0.0864	56.0	1.289	0.5404	0.0716	0.0248

*No tailwater

TABLE IV. SUMMARY OF FRICTION MEASUREMENTS FOR 48-INCH HELICAL PIPE WITH 2-INCH BY 1/2-INCH CORRUGATIONS

Average measured diameter = 4.0392 ft

Q cfs	$\bar{V}$ fps	S per cent	Water Temp. Deg. F	ν ft^2/sec x 10^5	Re x 10^{-6}	Darcy f	Manning n
189.74*	14.807	4.3271	54.0	1.328	4.5038	0.0513	0.0210
185.17*	14.451	4.2106	54.0	1.328	4.3953	0.0524	0.0212
179.94	14.043	4.0858	56.0	1.289	4.4004	0.0538	0.0215
178.12*	13.901	4.0025	54.0	1.328	4.2279	0.0538	0.0215
177.01	13.814	3.9027	56.0	1.289	4.3287	0.0532	0.0214
171.23	13.363	3.6947	55.0	1.307	4.1297	0.0538	0.0215
171.01*	13.346	3.5366	54.0	1.328	4.0592	0.0516	0.0211
168.74	13.169	3.6530	56.0	1.289	4.1265	0.0548	0.0217
155.92	12.168	3.1205	56.0	1.289	3.8130	0.0548	0.0217
148.09	11.557	2.8916	54.0	1.328	3.5151	0.0563	0.0220
135.01	10.536	2.4548	54.0	1.328	3.2047	0.0575	0.0222
130.94	10.219	2.0528	54.0	1.328	3.1080	0.0511	0.0210
122.54	9.563	1.8391	54.0	1.328	2.9087	0.0523	0.0212
116.21	9.069	1.7100	56.0	1.289	2.8419	0.0540	0.0216
104.02	8.118	1.3381	56.0	1.289	2.5438	0.0528	0.0213
91.83	7.166	1.0302	56.0	1.289	2.2457	0.0521	0.0212
89.28	6.967	0.9903	56.0	1.289	2.1833	0.0530	0.0214
80.91	6.314	0.8321	56.0	1.289	1.9786	0.0542	0.0216
70.97	5.539	0.5875	56.0	1.289	1.7356	0.0498	0.0207
54.89	4.284	0.3349	57.0	1.271	1.3613	0.0474	0.0202
37.94	2.961	0.1885	56.0	1.289	0.9278	0.0559	0.0219
21.12	1.648	0.0468	55.0	1.307	0.5094	0.0448	0.0196

*No tailwater

TABLE V. SUMMARY OF FRICTION MEASUREMENTS FOR 48-INCH HELICAL PIPE WITH 2-2/3-INCH BY 1/2-INCH CORRUGATIONS

Average measured diameter = 3.9760 ft

Q cfs	$\bar{V}$ fps	S per cent	Water Temp. Deg. F	ν ft^2/sec x 10^5	Re x 10^{-6}	Darcy f	Manning n
193.90*	15.617	4.5358	41.0	1.637	3.7931	0.0476	0.0202
189.40*	15.254	4.3027	44.0	1.555	3.9004	0.0473	0.0201
184.89*	14.891	4.1779	44.0	1.555	3.8075	0.0482	0.0203
181.23	14.596	3.9365	42.0	1.610	3.6047	0.0473	0.0201
178.02*	14.338	3.8700	44.0	1.555	3.6661	0.0482	0.0203
174.57*	14.060	3.6952	42.0	1.610	3.4722	0.0478	0.0202
170.88	13.763	3.5953	42.0	1.610	3.3988	0.0486	0.0204
169.24*	13.631	3.5037	44.0	1.555	3.4852	0.0482	0.0203
163.89*	13.200	3.2957	42.0	1.610	3.2598	0.0484	0.0204
158.58	12.772	3.1002	43.0	1.582	3.2100	0.0486	0.0204
149.42	12.034	2.8854	43.0	1.582	3.0246	0.0510	0.0209
148.59*	11.968	2.8296	44.0	1.555	3.0600	0.0506	0.0208
140.66	11.329	2.4161	42.0	1.610	2.7978	0.0482	0.0203
132.60	10.630	2.1389	42.0	1.610	2.6374	0.0480	0.0203
126.77	10.210	2.0282	43.0	1.582	2.5661	0.0498	0.0206
124.34	10.014	1.8850	42.0	1.610	2.4731	0.0481	0.0203
113.73	9.160	1.5563	42.0	1.610	2.2621	0.0475	0.0202
101.52	8.176	1.2983	42.0	1.610	2.0192	0.0497	0.0206
88.68	7.142	0.9695	42.0	1.610	1.7638	0.0486	0.0204
73.39	5.911	0.6774	42.0	1.610	1.4597	0.0496	0.0206
55.20	4.446	0.3970	42.0	1.610	1.0979	0.0514	0.0210
35.46	2.856	0.1540	42.0	1.610	0.7053	0.0483	0.0203
21.60	1.740	0.0600	40.0	1.664	0.4157	0.0507	0.0208

*No tailwater

TABLE VI. SUMMARY OF FRICTION MEASUREMENTS FOR 24-INCH HELICAL PIPE WITH 2-2/3-INCH BY 1/2-INCH CORRUGATIONS

Average measured diameter = 1.9950 ft

Q cfs	$\bar{V}$ fps	S per cent	Water Temp. Deg. F	ν ft^2/sec x 10^5	Re x 10^{-6}	Darcy f	Manning n
38.417*	12.290	4.9598	33.0	1.895	1.2938	0.0422	0.0169
37.847	12.108	4.7344	34.0	1.859	1.2993	0.0415	0.0168
36.425*	11.653	4.4422	33.0	1.895	1.2268	0.0420	0.0169
36.068	11.538	4.3837	33.0	1.895	1.2147	0.0423	0.0170
33.661	10.768	3.8576	34.0	1.859	1.1556	0.0427	0.0171
31.311*	10.017	3.2815	33.0	1.895	1.0545	0.0420	0.0169
30.590	9.786	3.0977	34.0	1.859	1.0502	0.0415	0.0168
28.242	9.035	2.6969	34.0	1.859	0.9696	0.0424	0.0170
26.198	8.381	2.1877	33.0	1.895	0.8823	0.0400	0.0165
26.102*	8.350	2.2879	33.0	1.895	0.8791	0.0421	0.0169
24.896	7.964	2.0707	34.0	1.859	0.8547	0.0419	0.0169
21.101	6.750	1.5196	34.0	1.859	0.7244	0.0428	0.0171
19.982*	6.392	1.3443	33.0	1.895	0.6730	0.0422	0.0170
17.558	5.617	1.0236	34.0	1.859	0.6028	0.0416	0.0168
15.304	4.896	0.7932	34.0	1.859	0.5254	0.0425	0.0170
13.688	4.379	0.6397	34.0	1.859	0.4699	0.0428	0.0171
12.226	3.911	0.5010	34.0	1.859	0.4197	0.0420	0.0169
10.594	3.389	0.3707	34.0	1.859	0.3637	0.0414	0.0168
9.168	2.933	0.2856	34.0	1.859	0.3148	0.0426	0.0170
7.606	2.433	0.1970	34.0	1.859	0.2611	0.0427	0.0170
6.348	2.031	0.1252	34.0	1.859	0.2179	0.0390	0.0163
4.820	1.542	0.0836	34.0	1.859	0.1655	0.0451	0.0175
4.546	1.454	0.0836	34.0	1.859	0.1561	0.0507	0.0186
2.649	0.847	0.0274	34.0	1.859	0.0909	0.0491	0.0183

*Downstream valve removed

TABLE VII. SUMMARY OF FRICTION MEASUREMENTS FOR 12-INCH HELICAL PIPE WITH 2-2/3-INCH BY 1/2-INCH CORRUGATIONS

Average measured diameter = 0.9781 ft

Q cfs	$\bar{V}$ fps	S per cent	Water Temp. Deg. F	ν ft^2/sec x 10^5	Re x 10^{-6}	Darcy f	Manning n
11.662*	15.521	8.6161	34.0	1.859	0.8166	0.0225	0.0110
11.310	15.052	8.1385	34.0	1.859	0.7920	0.0226	0.0110
11.194	14.898	7.9242	35.0	1.823	0.7993	0.0225	0.0110
10.887	14.489	7.6276	35.0	1.823	0.7774	0.0229	0.0111
10.704	14.246	7.4135	34.0	1.859	0.7495	0.0230	0.0111
10.454*	13.913	6.9357	34.0	1.859	0.7320	0.0226	0.0110
10.449	13.906	6.9851	34.0	1.859	0.7317	0.0227	0.0110
10.113	13.459	6.1449	34.0	1.859	0.7081	0.0214	0.0107
9.226	12.279	5.4202	34.0	1.859	0.6460	0.0226	0.0110
9.193*	12.235	5.4860	34.0	1.859	0.6437	0.0231	0.0111
8.754	11.651	4.9754	34.0	1.859	0.6130	0.0231	0.0111
7.930	11.554	4.1021	35.0	1.823	0.5662	0.0232	0.0112
7.716	10.269	3.9209	35.0	1.823	0.5510	0.0234	0.0112
7.246*	9.644	3.4513	34.0	1.859	0.5074	0.0234	0.0112
6.856	9.125	3.1054	34.0	1.859	0.4801	0.0235	0.0112
6.566	8.739	2.7677	35.0	1.823	0.4689	0.0228	0.0111
5.396	7.181	1.9226	35.0	1.823	0.3853	0.0235	0.0112
4.937*	6.571	1.6507	34.0	1.859	0.3457	0.0241	0.0114
3.801	5.059	0.9786	35.0	1.823	0.2714	0.0241	0.0114
3.128	4.163	0.6836	35.0	1.823	0.2234	0.0248	0.0115
2.606	3.468	0.4909	35.0	1.823	0.1861	0.0257	0.0117
2.100	2.795	0.3296	36.0	1.791	0.1526	0.0265	0.0119
1.784	2.374	0.2194	35.0	1.823	0.1274	0.0245	0.0115
1.680	2.236	0.2072	36.0	1.791	0.1211	0.0261	0.0118
1.452	1.932	0.1645	36.0	1.791	0.1055	0.0277	0.0122
1.254	1.669	0.1071	35.0	1.823	0.0895	0.0243	0.0114
1.193	1.588	0.1020	36.0	1.791	0.0867	0.0255	0.0117
0.966	1.286	0.0656	35.0	1.823	0.0690	0.0250	0.0116
0.948	1.262	0.0656	36.0	1.791	0.0689	0.0260	0.0118
0.660	0.878	0.0329	35.0	1.823	0.0471	0.0269	0.0120
0.626	0.833	0.0371	36.0	1.791	0.0455	0.0336	0.0134

*Downstream valve removed

TABLE VII. [Continued] SUMMARY OF FRICTION MEASUREMENTS FOR 12-INCH HELICAL PIPE WITH 2-2/3-INCH BY 1/2-INCH CORRUGATIONS

Average measured diameter = 0.9781 ft

Q cfs	$\bar{V}$ fps	S per cent	Water Temp. Deg. F	ν ft^2/sec x 10^5	Re x 10^{-6}	Darcy f	Manning n
11.718*	15.595	8.9620	53.0	1.348	1.1316	0.0232	0.0112
11.422*	15.201	8.4678	53.0	1.348	1.1030	0.0231	0.0111
11.166*	14.861	8.0724	53.0	1.348	1.0783	0.0230	0.0111
10.512*	13.990	7.2817	53.0	1.348	1.0151	0.0234	0.0112
9.982*	13.285	6.4909	53.0	1.348	0.9639	0.0232	0.0111

*Downstream valve removed

TABLE VIII. FRICTION FACTORS AT HIGH REYNOLDS NUMBERS AND OTHER DATA

	PIPE DATA								FRICTION FACTORS			
Ref.	Dia. D ft	Corrugation p x d In.	Helix Angle θ Deg	p/d	d/D	Nom. sheet width in.	Material	Graph symbol	f	n	$\frac{fD^{0.41}}{0.122}$	$\frac{fD^{0.41}}{0.945\ \theta^{3.64}} \times 10^8$
						a. Present Tests						
	0.978	$2\frac{2}{3}$ x 0.496	$52\frac{1}{2}$	5.37	0.0424	24	Aluminum	⊡	0.023	0.0111	0.1885	1.340
	1.995	$2\frac{2}{3}$ x 0.519	$72\frac{1}{4}$	5.15	0.0216	24	"	⊡	0.042	0.0169	0.457	1.022
	3.976	$2\frac{2}{3}$ x 0.517	81	5.15	0.0108	24	"	⊡	0.048	0.0204	0.694	1.023
	4.039	2 x 0.490	$82\frac{1}{2}$	4.08	0.0101	20	"	○	0.053	0.0214	0.770	1.060
	3.97	6 x 0.941	90	6.36	0.0198	--	"	⊕	0.068	0.0242	0.981	--
	5.45	6 x 0.958	90	6.26	0.0146	--	"	⊕	0.062	0.0242	1.018	--
	5.38	9 x 2.484	90	3.62	0.040	--	"	⊕	0.137	0.0360	--	--
						b. Previous Tests						
[1]	0.993	2 x 0.460	$59\frac{1}{2}$	4.35	0.0386	20	Aluminum	⊙	0.0272	0.0122	0.223	1.009
[1]	1.508	2 x 0.44	70	4.55	0.0243	20	"	⊙	0.036	0.015	0.350	0.876
[1]	1.998	2 x 0.449	75	4.45	0.0187	20	"	⊙	0.041	0.0167	0.446	0.884

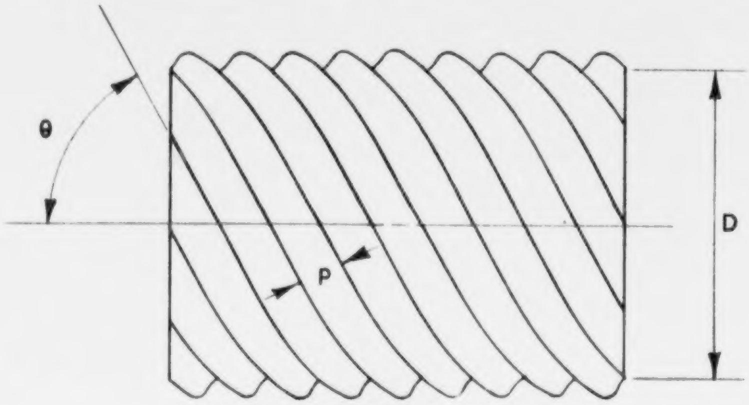
[3]	0.677	$1\frac{1}{2}$ x 0.24	62*	6.25	0.0295	12	Steel	◇	0.036	0.0130	0.252	0.973
[3]	1.00	2 x 0.43	66*	4.65	0.0358	16	"	◇	0.043	0.0152	0.352	1.090
[4]	1.01	2 x 0.44*	66*	4.55	0.0363	16	"	◈	0.040	0.0146	0.328	1.015
[4]	1.01	$2\frac{2}{3}$ x 0.5*	90	5.33	0.0412	--	"	◈	0.120	0.0254	0.985	--
[5]	1.51	$2\frac{2}{3}$ x 0.5*	90	5.33	0.0276	--	"	△	0.101#	0.0250	0.980	--
[5]	2.03	$2\frac{2}{3}$ x 0.5*	90	5.33	0.0205	--	"	△	0.092#	0.0250	1.006	--
[5]	3.00	$2\frac{2}{3}$ x 0.5*	90	5.33	0.0139	--	"	△	0.078#	0.0246	1.002	--
[6]	2.996	$2\frac{2}{3}$ x 0.5*	90	5.33	0.0139	--	"	▽	0.077#	0.0243	0.990	--
[6]	4.95	$2\frac{2}{3}$ x 0.5*	90	5.33	0.0084	--	"	▽	0.0638#	0.0242	1.007	--
[6]	7.05	$2\frac{2}{3}$ x 0.5*	90	5.33	0.0059	--	"	▽	0.0538#	0.0235	0.984	--
[7]	1.25*	$2\frac{2}{3}$ x 0.5*	90	5.33	0.0333	--	"	⌖	0.114	0.0257	1.022	--
[7]	4.925*	6 x 2*	90	3.00	0.0338	--	" •	⌖	0.134#	0.0350	--	--

[1] Silberman and Dahlin, Friction Factors for Helical Corrugated Aluminum Pipe, P.R. 112, SAFHL, 1969.
[3] Rice, Friction Factors for Helical Corrugated Pipe, ARS 41-119, ARS, USDA, 1966.
[4] Chamberlain, disc. of [6], Jr. Hydr. Div., ASCE, Vol. 86, No. HY3, March 1960, pp. 67-74.
[5] Straub and Morris, Hydraulic Tests on Corrugated Metal Culvert Pipes, T.P. 5-B, SAFHL, 1950.
[6] Webster and Metcalf, "Friction Factors in Corrugated Metal Pipes," Jr. Hydr. Div., ASCE, Sept. 1959, pp. 35-67.
[7] Neill, "Hydraulic Roughness of Corrugated Pipes," Jr. Hydr. Div. ASCE, May 1962, pp. 23-44, and disc. closure July 1963, pp. 205-208.

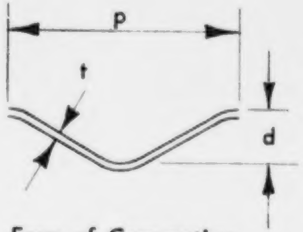
*Nominal, not known whether measurement was made. Otherwise, measured.

#Maximum value (at high Reynolds number).

•Bolted joints. All other annular pipe riveted. Helical pipe has crimped seams.



Corrugated Pipe



Form of Corrugation

From Factory Specifications						Measured			
Type	Nominal Pipe Dia. in.	Helix Angle θ - Deg - Min	p - in.	t - in.	d - in.	Average Measured Dia. - D - in.	Standard Deviation in.	Helix Angle θ - Deg	d - in.
*Annular Riveted	66	90	6	0.105	1	65.42	0.719	90	0.958
*Annular Bolted	66	90	9	0.100	2-1/2	64.57	0.492	90	2.484
*Annular Riveted	48	90	6	0.075	1	47.62	0.332	90	0.941
*Helical	48	82° - 28'	2	0.105	1/2	48.47	0.204	82.5	0.490
#Helical	48	80° - 58'	2-2/3	0.105	1/2	47.71	0.218	81.0	0.517
#Helical	24	71° - 58'	2-2/3	0.105	1/2	23.94	0.099	72.2	0.519
#Helical	12	50° - 51'	2-2/3	0.060	1/2	11.737	0.030	52.5	0.496

*Supplied by Kaiser Aluminum & Chemical Sales, Inc.
#Supplied by Reynolds Metals Co.

Fig. 1 - Pipe Details

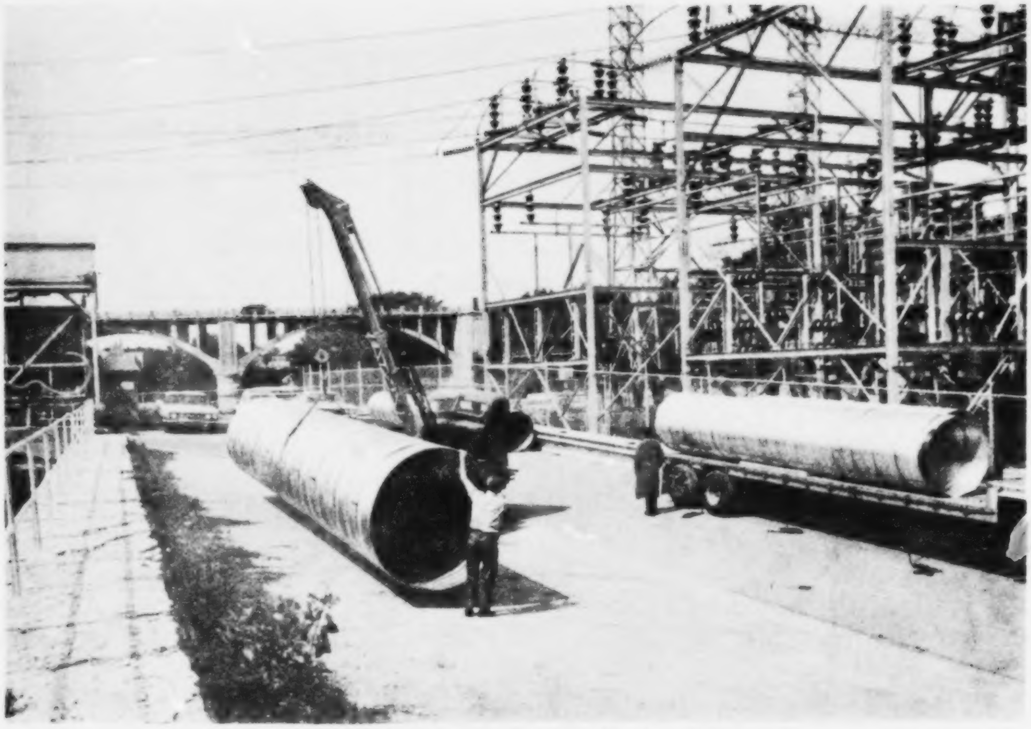


Fig. 2 - Unloading the 48 in. Pipe

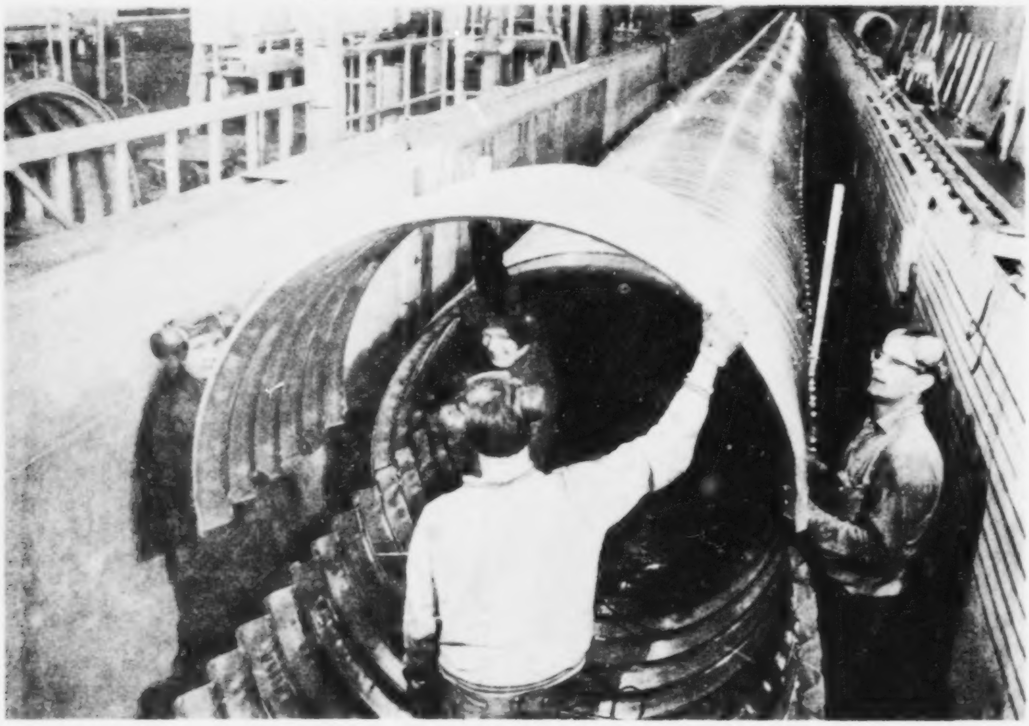


Fig. 3 - Assembly of the 66 in. Bolted Pipe

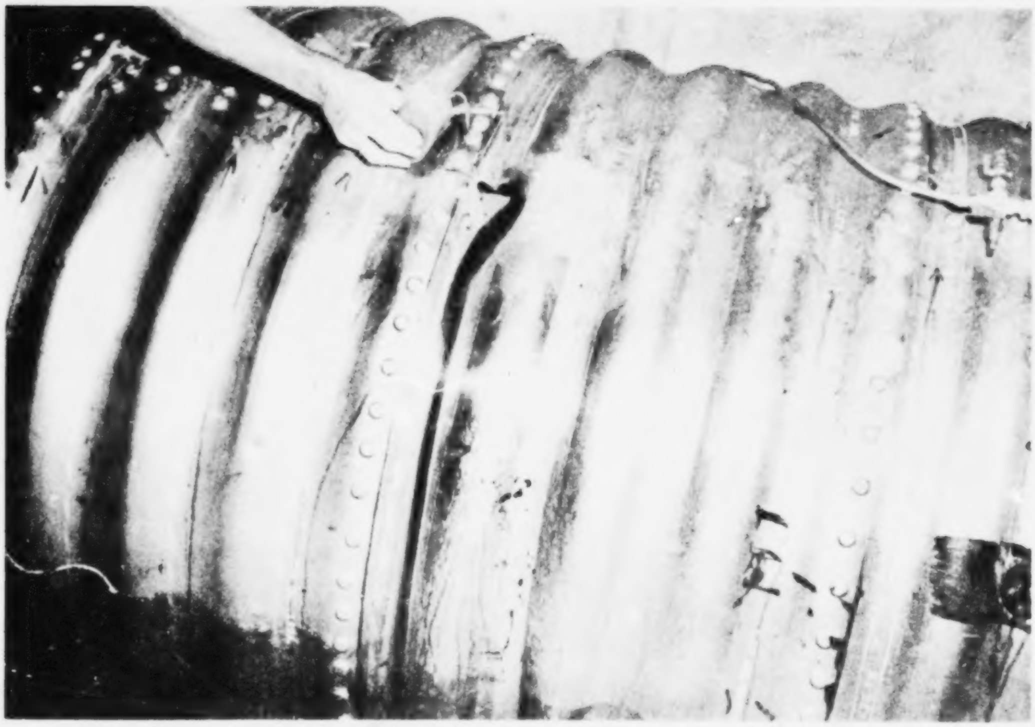


Fig. 4 - A Typical Leak in a Riveted Joint of the 48 in. Annular Pipe (Dye colors the leaking water)

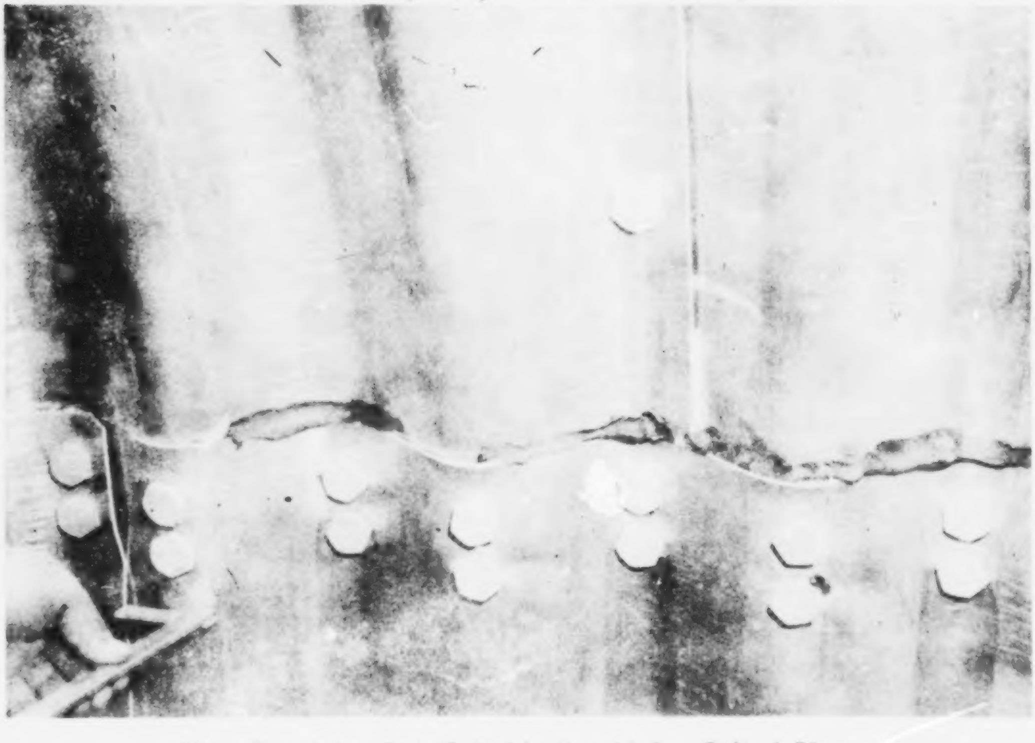
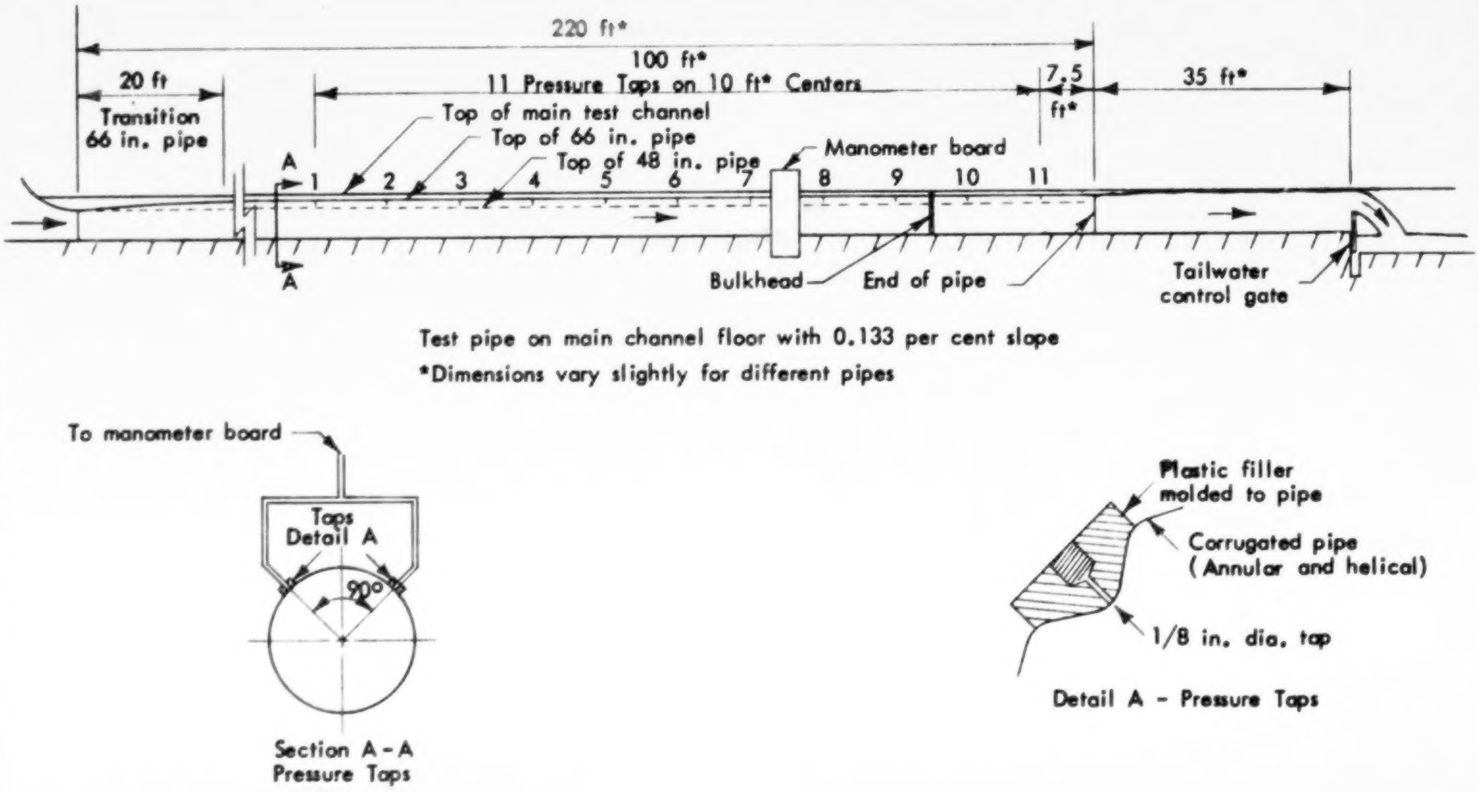


Fig. 5 - Joint Detail inside the 66 in. Bolted Pipe


220 ft*
100 ft*
11 Pressure Taps on 10 ft* Centers
20 ft
Transition
66 in. pipe
7.5
ft*
35 ft*
Top of main test channel
Top of 66 in. pipe
Top of 48 in. pipe
Manometer board
A
A
1
2
3
4
5
6
7
8
9
10
11
Bulkhead
End of pipe
Tailwater
control gate
To manometer board
Taps
Detail A
90°
Section A - A
Pressure Taps
Plastic filler
molded to pipe
Corrugated pipe
(Annular and helical)
1/8 in. dia. tap
Detail A - Pressure Taps

Test pipe on main channel floor with 0.133 per cent slope

*Dimensions vary slightly for different pipes

Fig. 6 - Test Arrangement in Main Test Channel for 48 in. and 66 in. Pipe

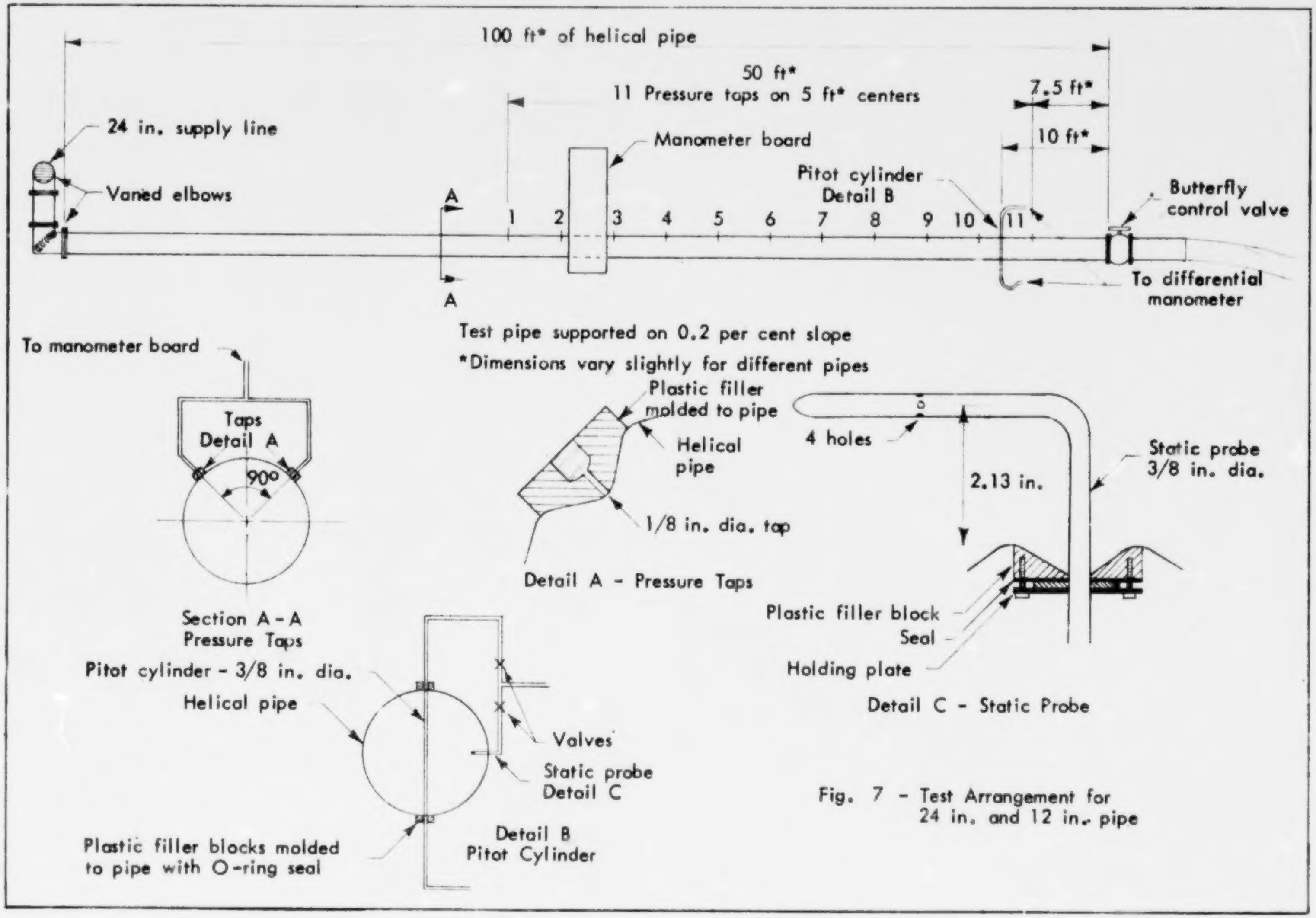

100 ft* of helical pipe
50 ft*
11 Pressure taps on 5 ft* centers
7.5 ft*
10 ft*
24 in. supply line
Manometer board
Vaned elbows
Pitot cylinder
Detail B
Butterfly
control valve
A
A
1
2
3
4
5
6
7
8
9
10
11
To differential
manometer
Test pipe supported on 0.2 per cent slope
*Dimensions vary slightly for different pipes
To manometer board
Taps
Detail A
90°
Plastic filler
molded to pipe
Helical
pipe
1/8 in. dia. tap
Detail A - Pressure Taps
4 holes
2.13 in.
Static probe
3/8 in. dia.
Plastic filler block
Seal
Holding plate
Detail C - Static Probe
Section A - A
Pressure Taps
Pitot cylinder - 3/8 in. dia.
Helical pipe
Valves
Static probe
Detail C
Detail B
Pitot Cylinder
Plastic filler blocks molded
to pipe with O-ring seal

Fig. 7 - Test Arrangement for 24 in. and 12 in. pipe

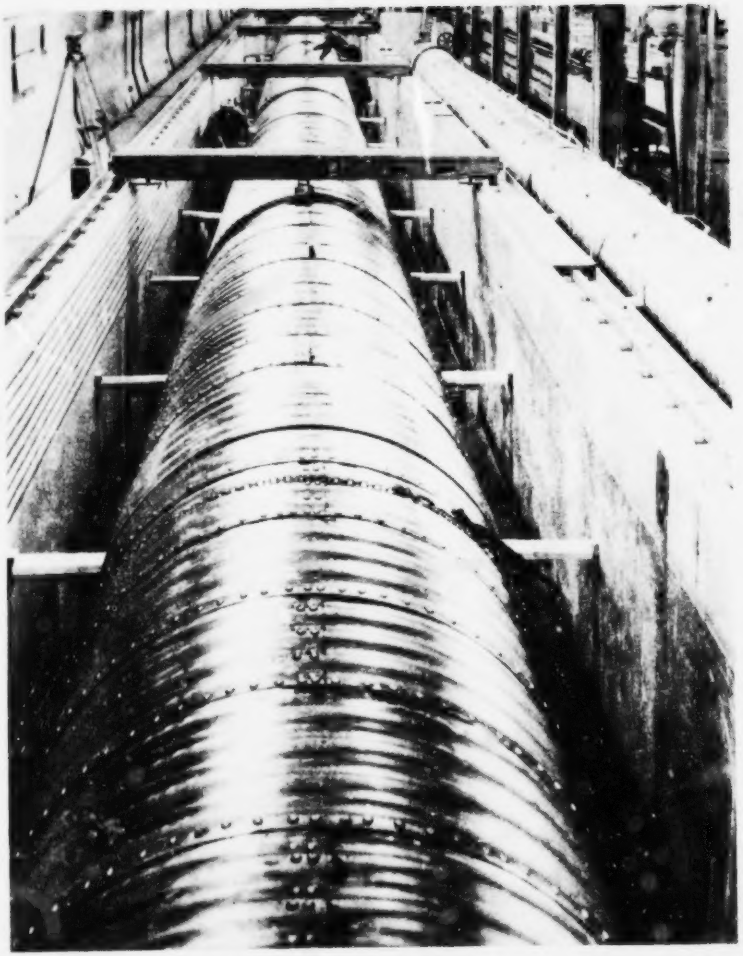


Fig. 8 - The 66 in. Annular Riveted Pipe Installed in the Main Channel with 24 in. Helical Pipe along the Side

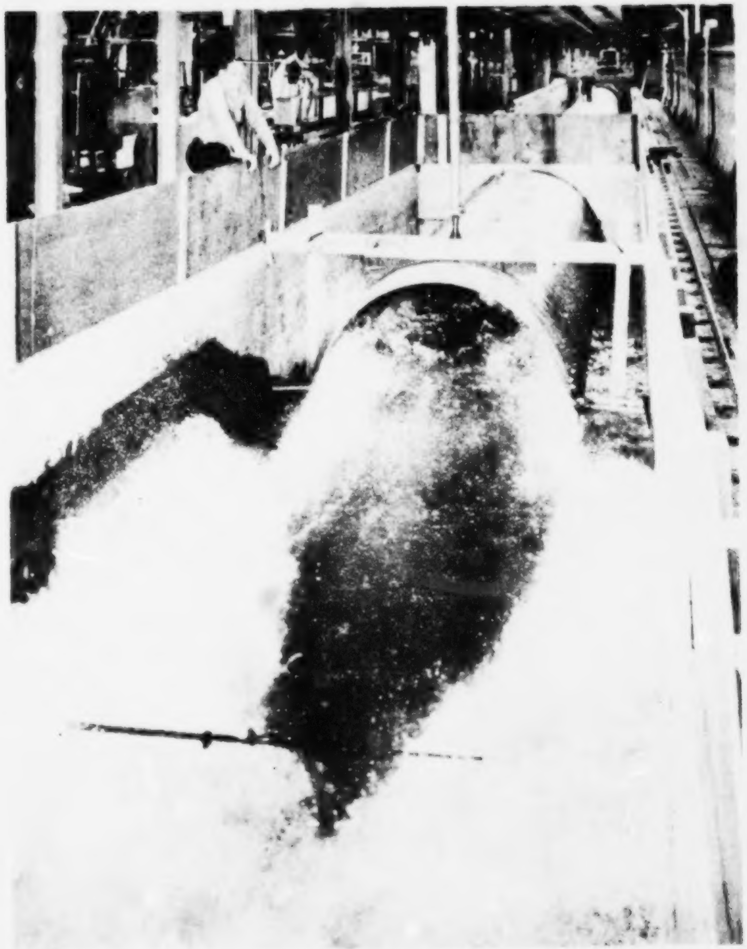


Fig. 9 - Flow at the Exit of the 66 in. Bolted Pipe (240 cfs)

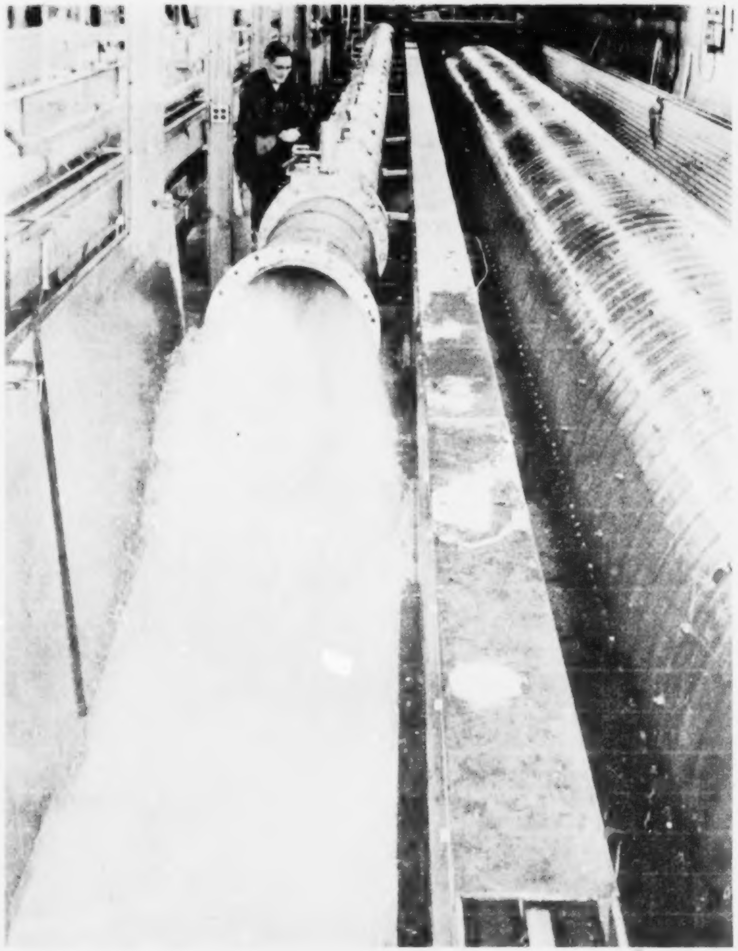


Fig. 10 - Flow at the Exit of the 24 in. Helical Pipe (38 cfs); 66 in. Bolted Pipe Installed in Main Channel along Side

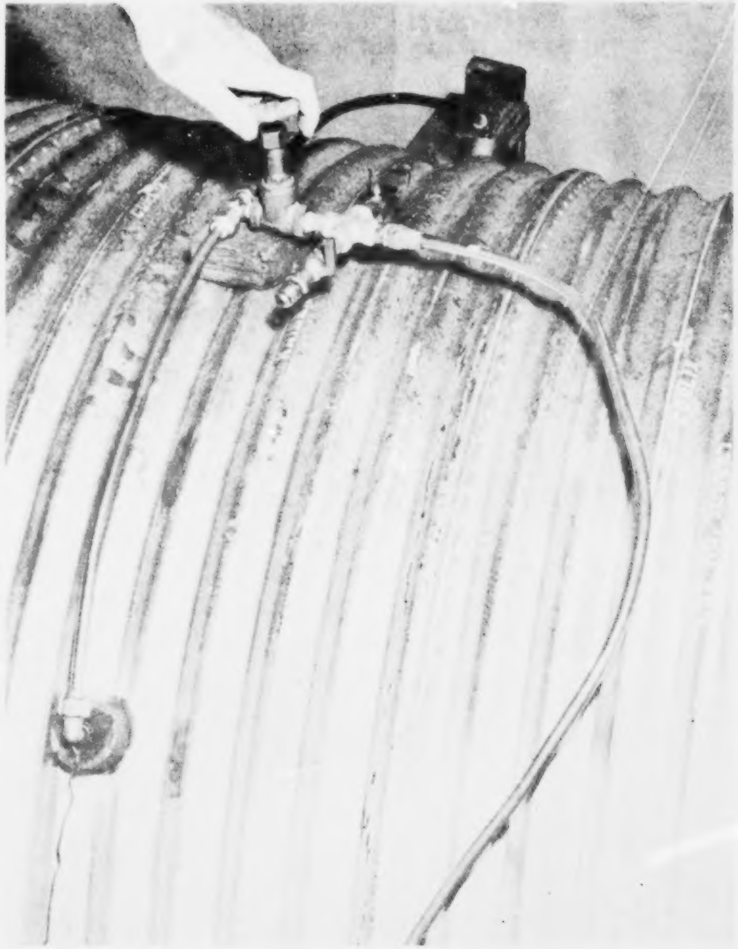


Fig. 11 - Piezometer Tap Arrangement (48 in. Helical Pipe)

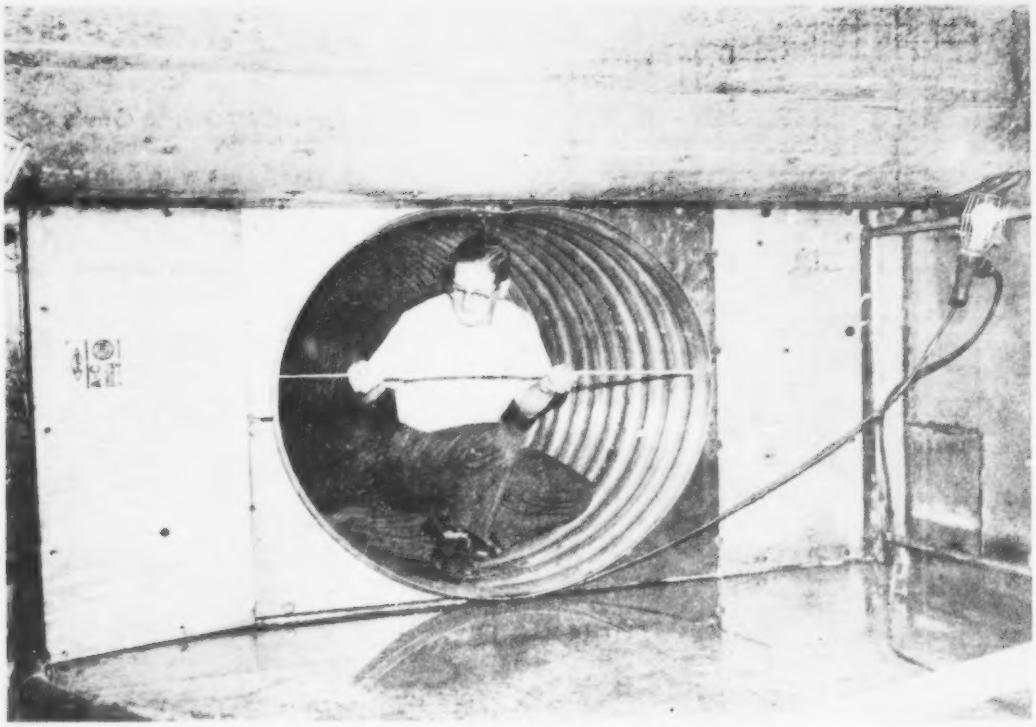


Fig. 12 - The Inlet for the 48 in. Pipes

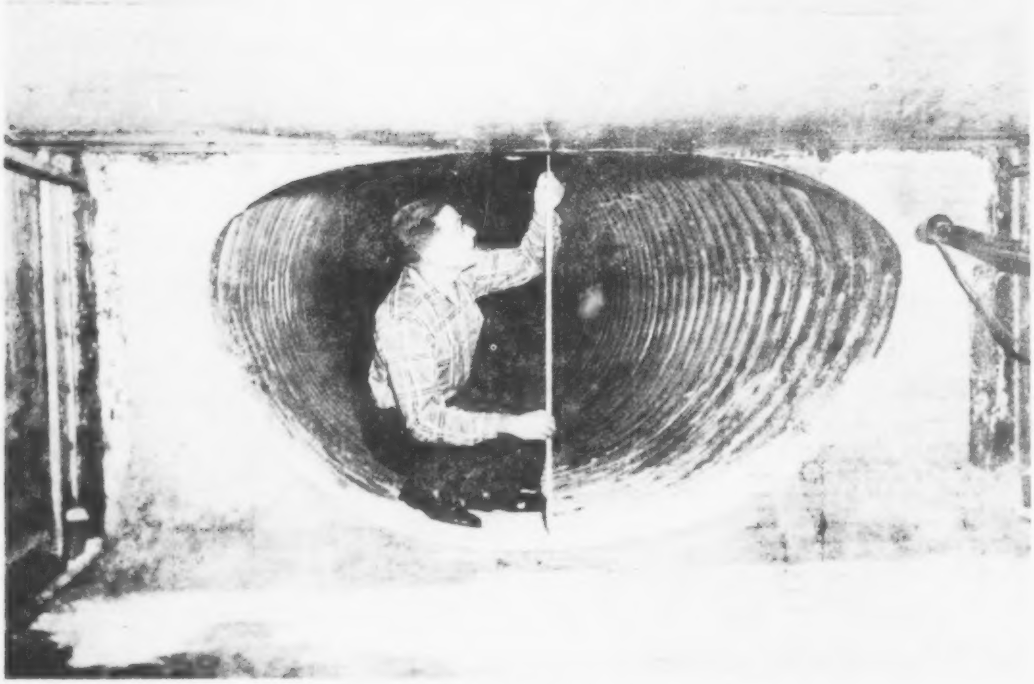


Fig. 13 - The Inlet for the 66 in. Pipes

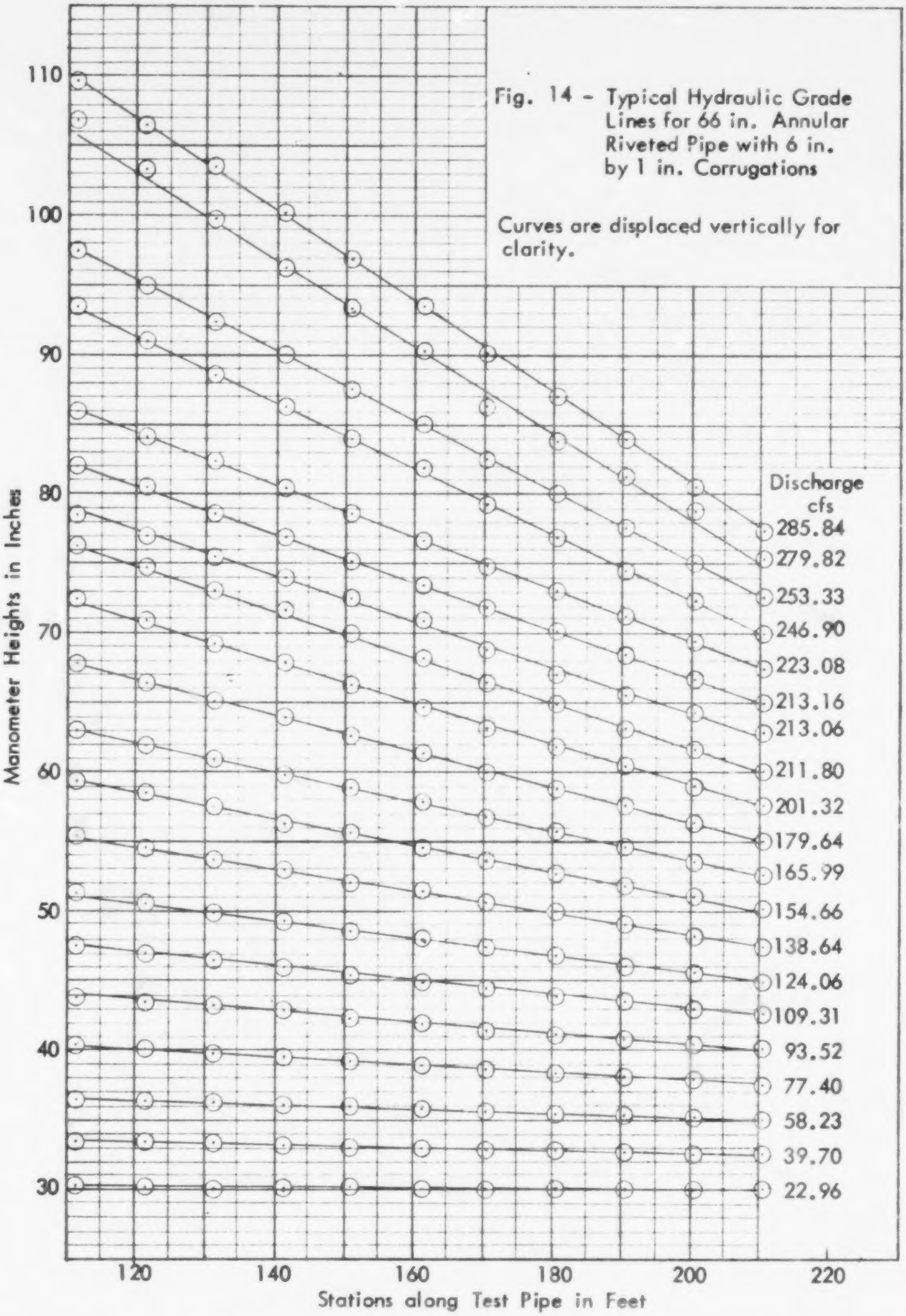


Fig. 14 - Typical Hydraulic Grade Lines for 66 in. Annular Riveted Pipe with 6 in. by 1 in. Corrugations

Curves are displaced vertically for clarity.

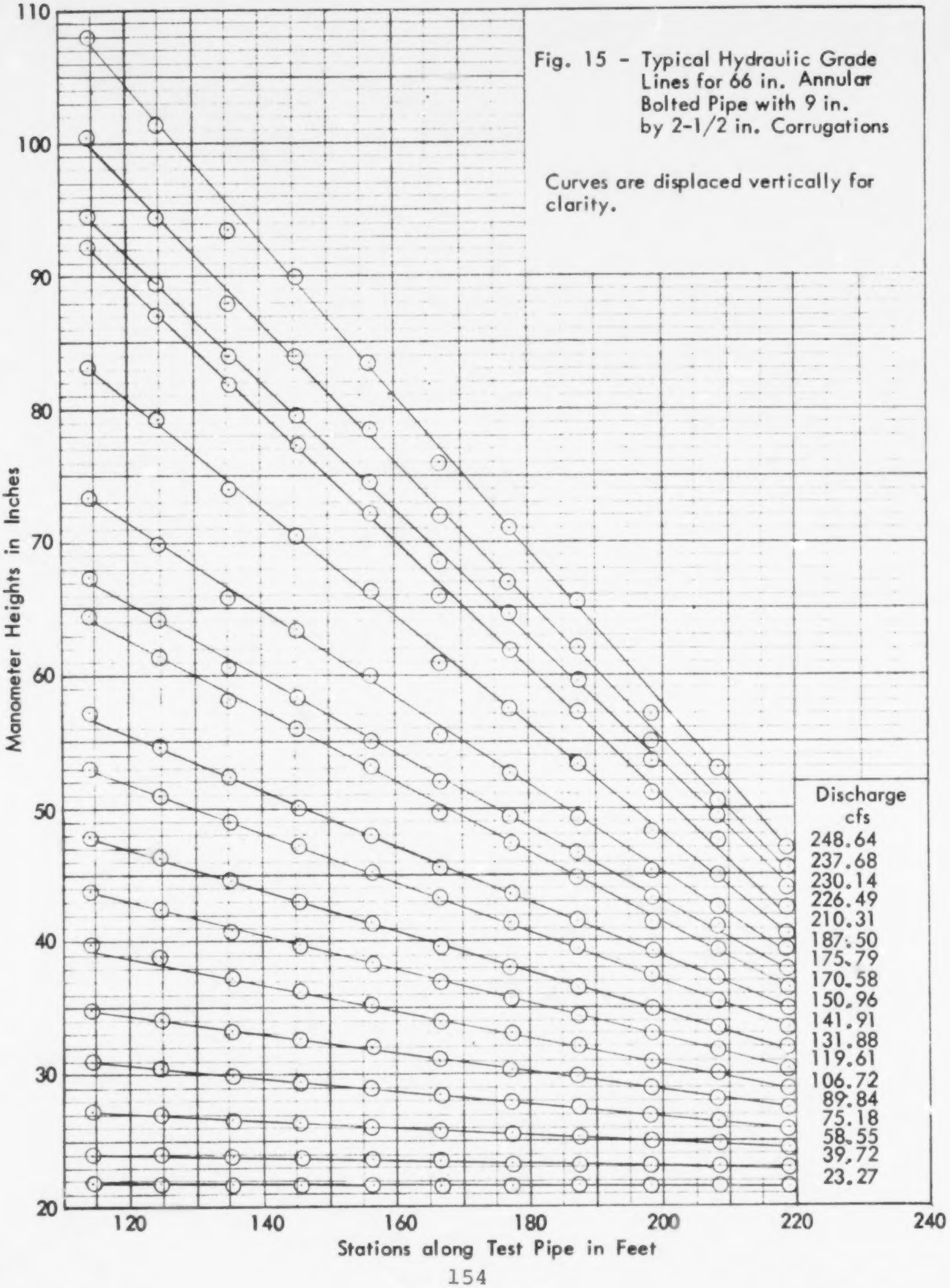


Fig. 15 - Typical Hydraulic Grade Lines for 66 in. Annular Bolted Pipe with 9 in. by 2-1/2 in. Corrugations

Curves are displaced vertically for clarity.

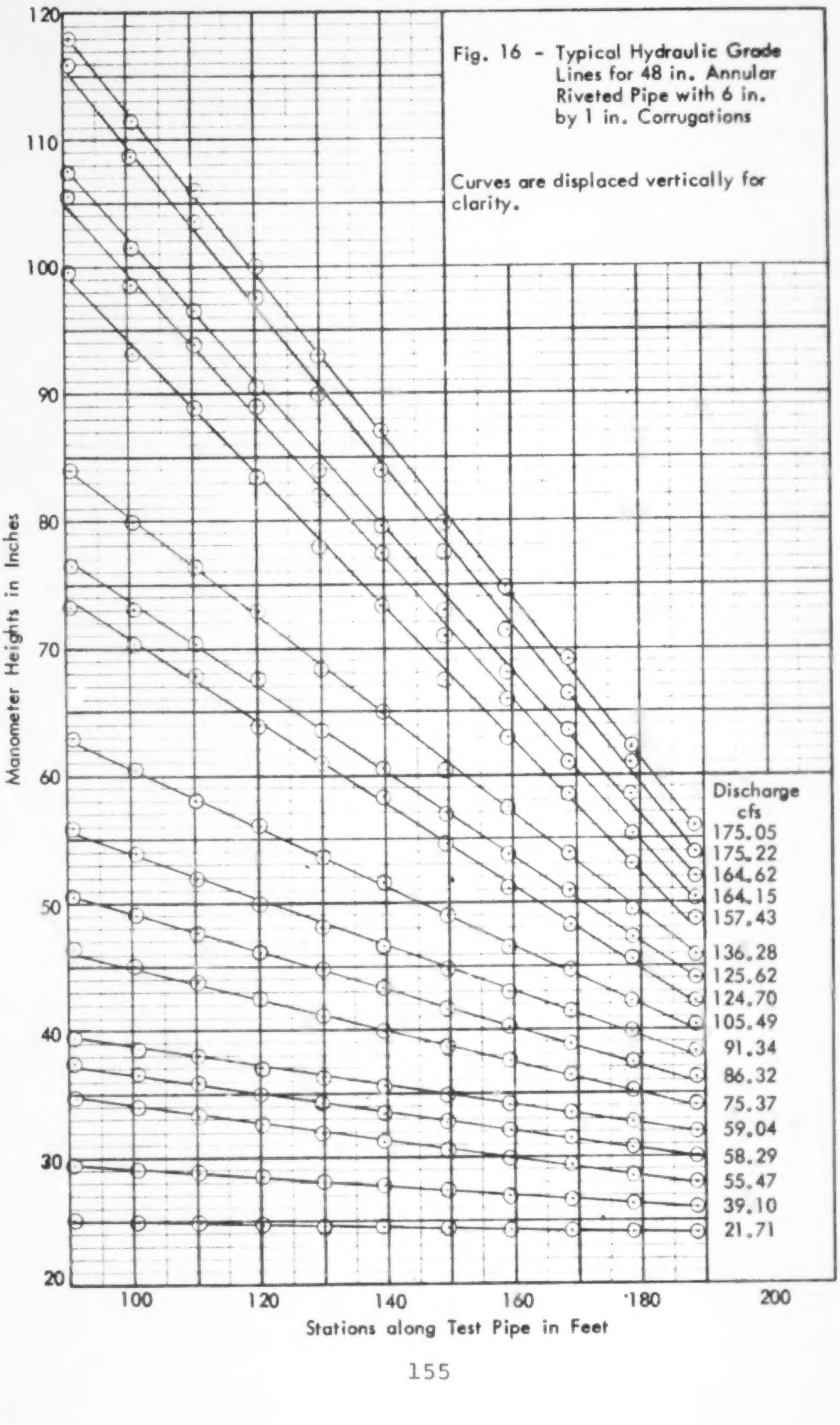


Fig. 16 - Typical Hydraulic Grade Lines for 48 in. Annular Riveted Pipe with 6 in. by 1 in. Corrugations

Curves are displaced vertically for clarity.

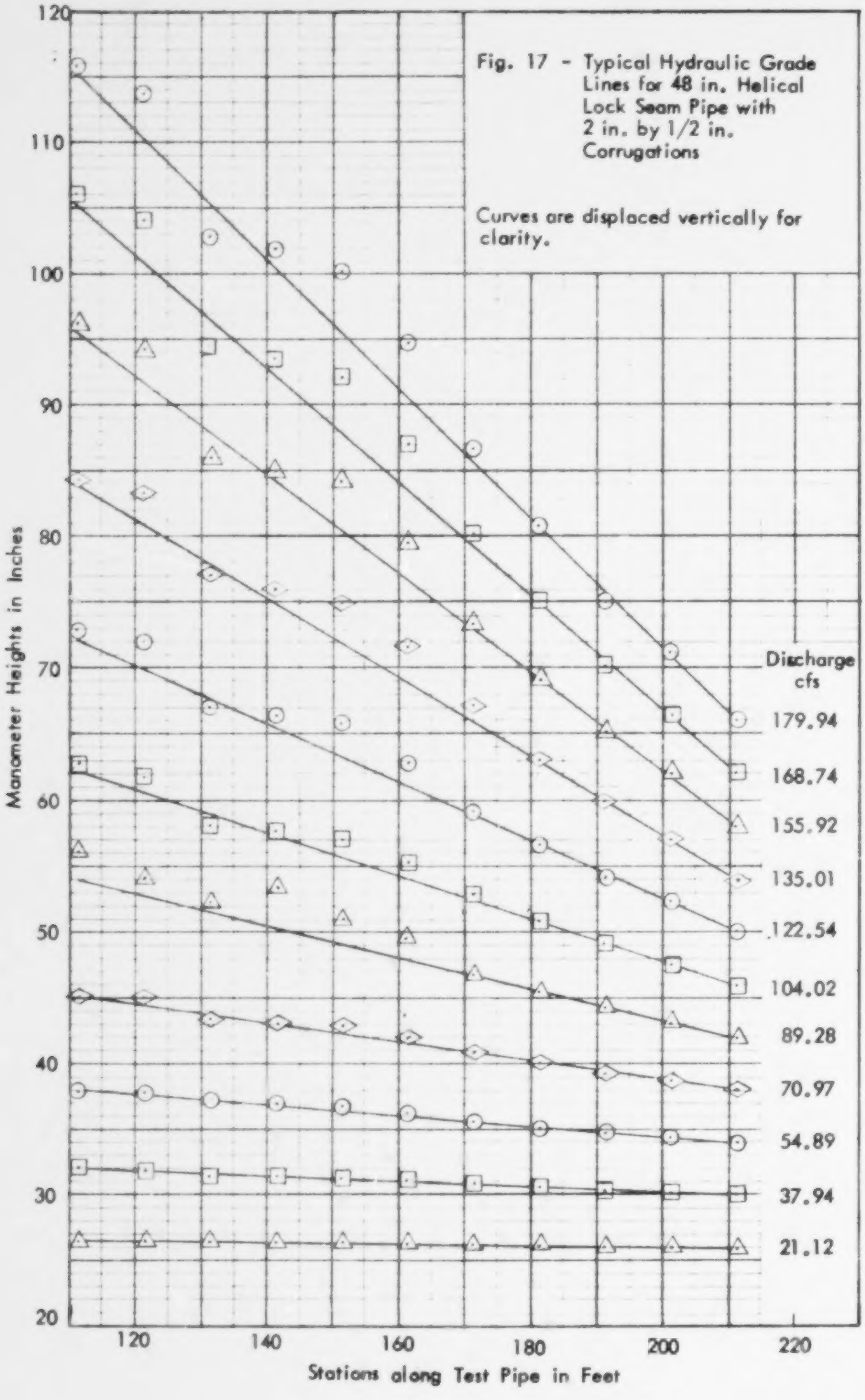


Fig. 17 - Typical Hydraulic Grade Lines for 48 in. Helical Lock Seam Pipe with 2 in. by 1/2 in. Corrugations

Curves are displaced vertically for clarity.

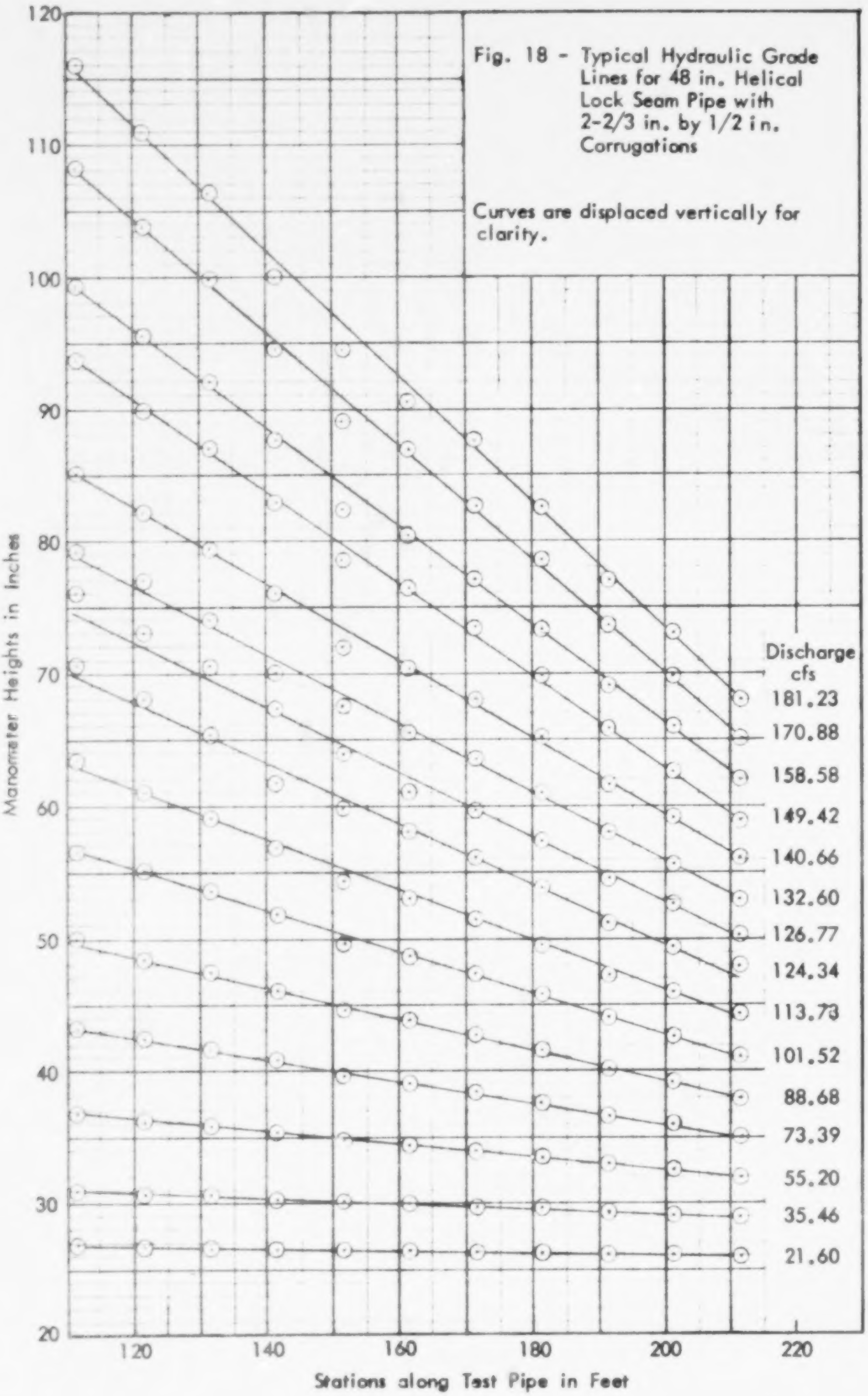


Fig. 18 - Typical Hydraulic Grade Lines for 48 in. Helical Lock Seam Pipe with 2-2/3 in. by 1/2 in. Corrugations

Curves are displaced vertically for clarity.

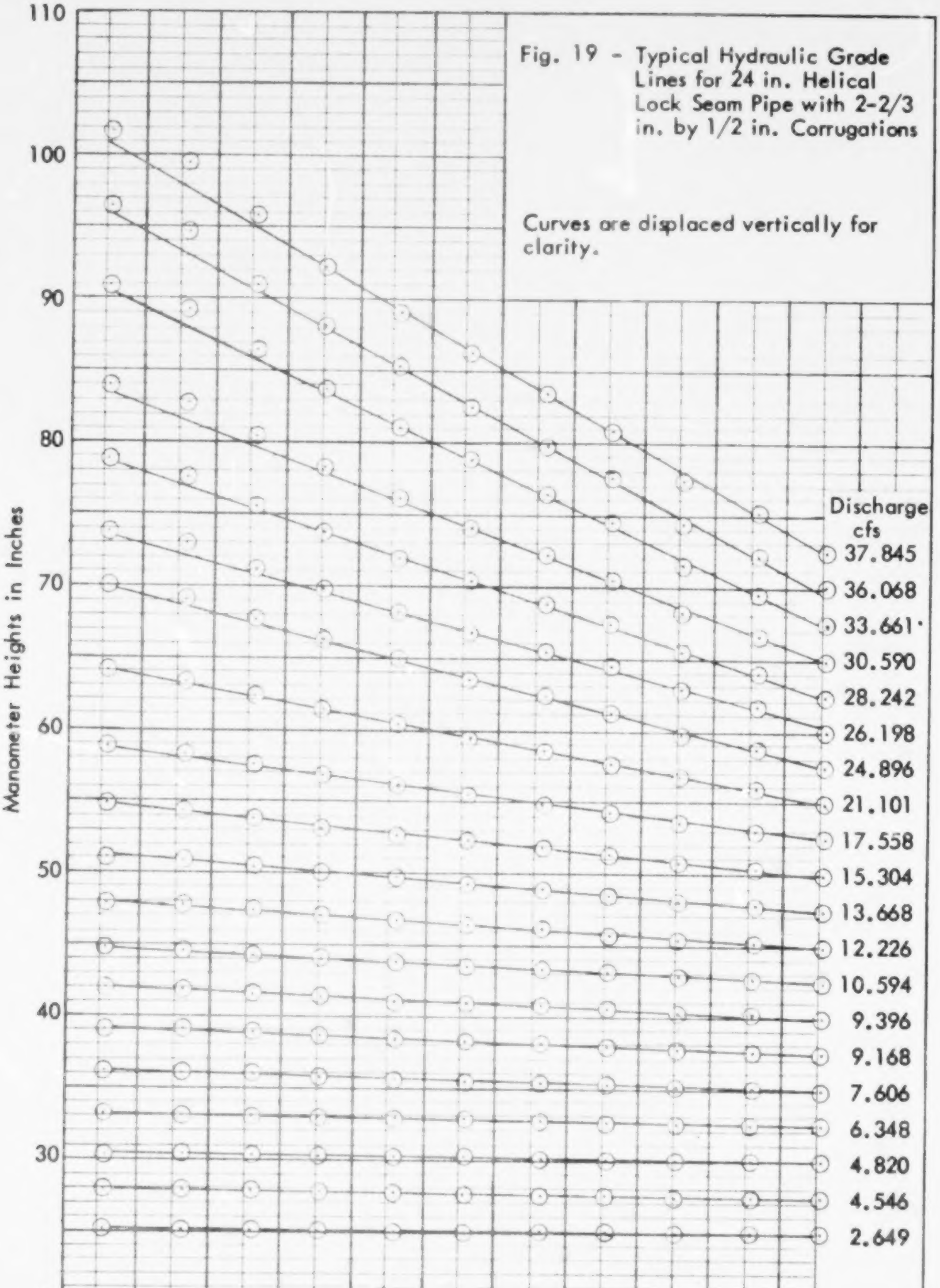


Fig. 19 - Typical Hydraulic Grade Lines for 24 in. Helical Lock Seam Pipe with 2-2/3 in. by 1/2 in. Corrugations
Curves are displaced vertically for clarity.
Discharge cfs
37.845
36.068
33.661
30.590
28.242
26.198
24.896
21.101
17.558
15.304
13.668
12.226
10.594
9.396
9.168
7.606
6.348
4.820
4.546
2.649
Manometer Heights in Inches
110
100
90
80
70
60
50
40
30
20
40
50
60
70
80
90
100
Stations along Test Pipe in Feet

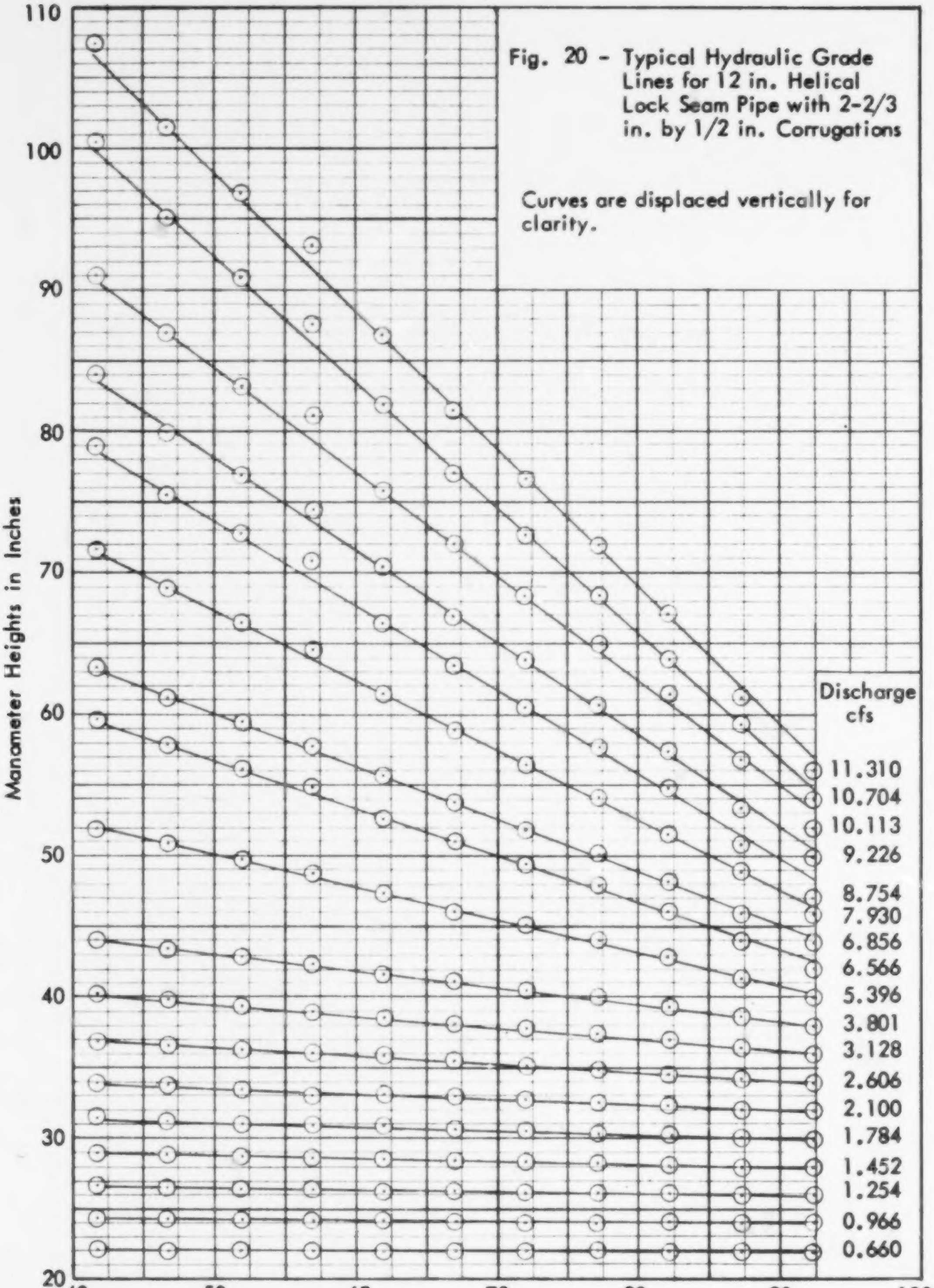


Fig. 20 - Typical Hydraulic Grade Lines for 12 in. Helical Lock Seam Pipe with 2-2/3 in. by 1/2 in. Corrugations

Curves are displaced vertically for clarity.

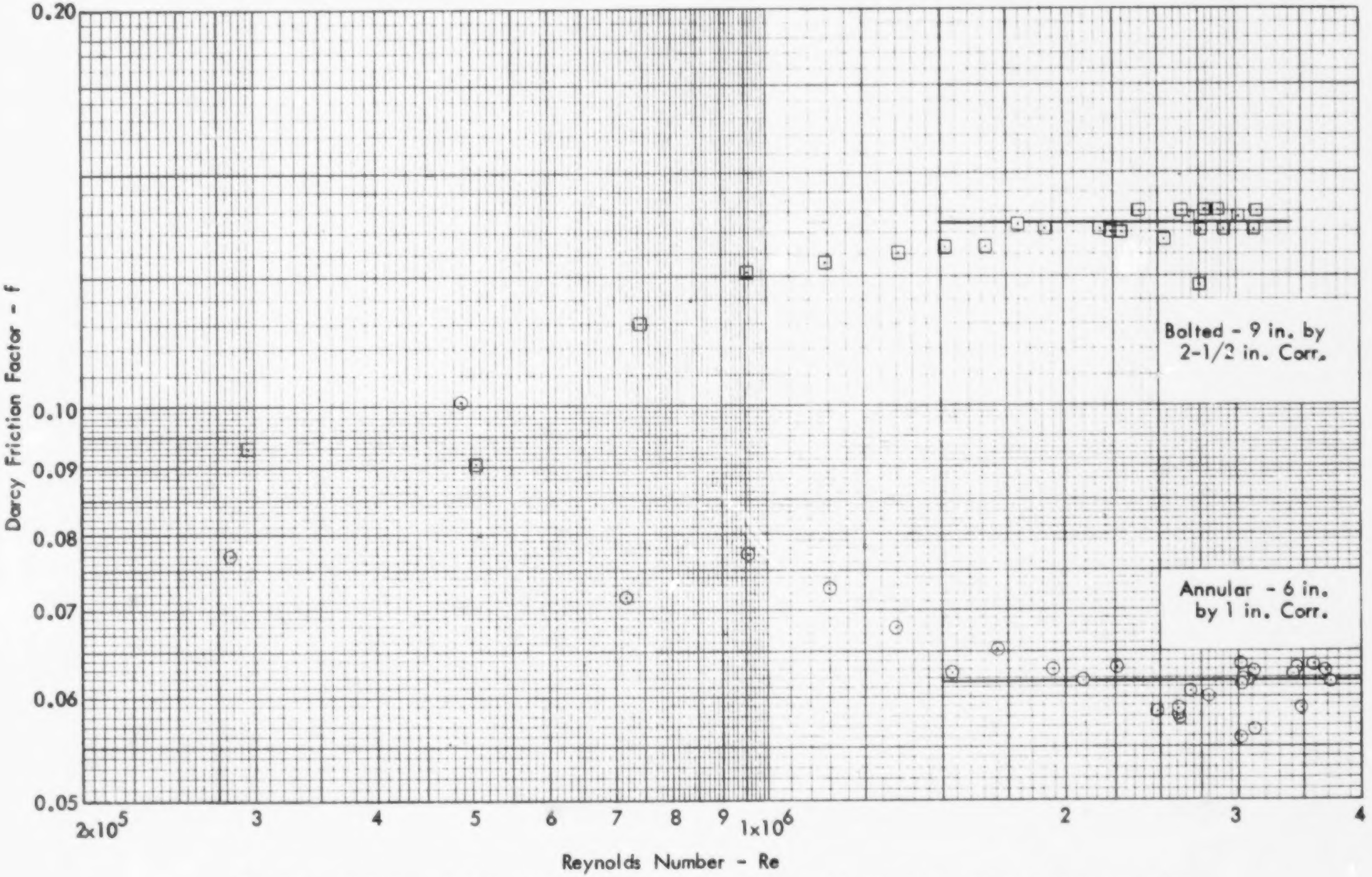


Fig. 21 - Variation of Darcy Friction Factor f with Reynolds Number - 66 Inch Corrugated Pipe

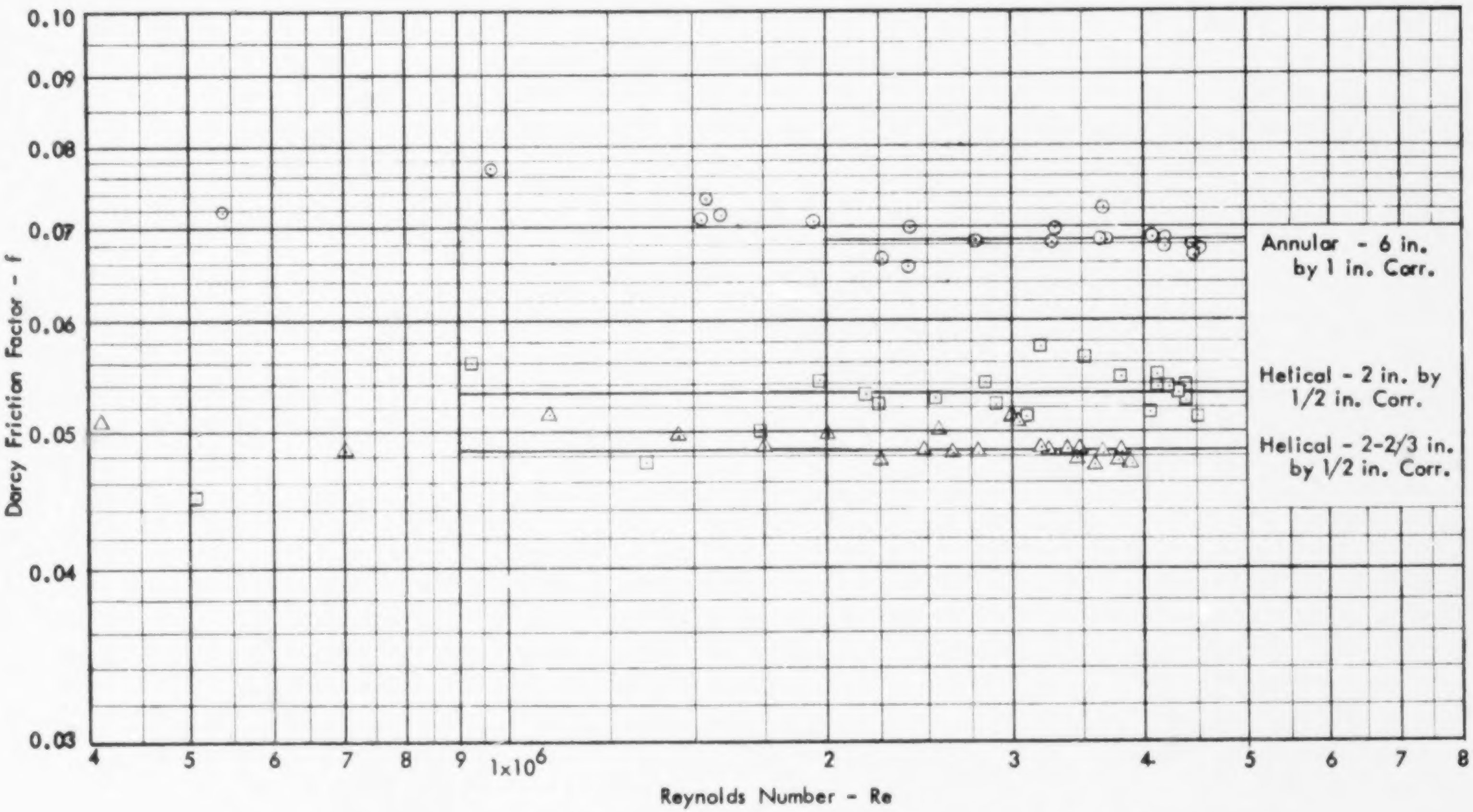


Fig. 22 - Variation of Darcy Friction Factor f with Reynolds Number - 48 Inch Corrugated Pipe

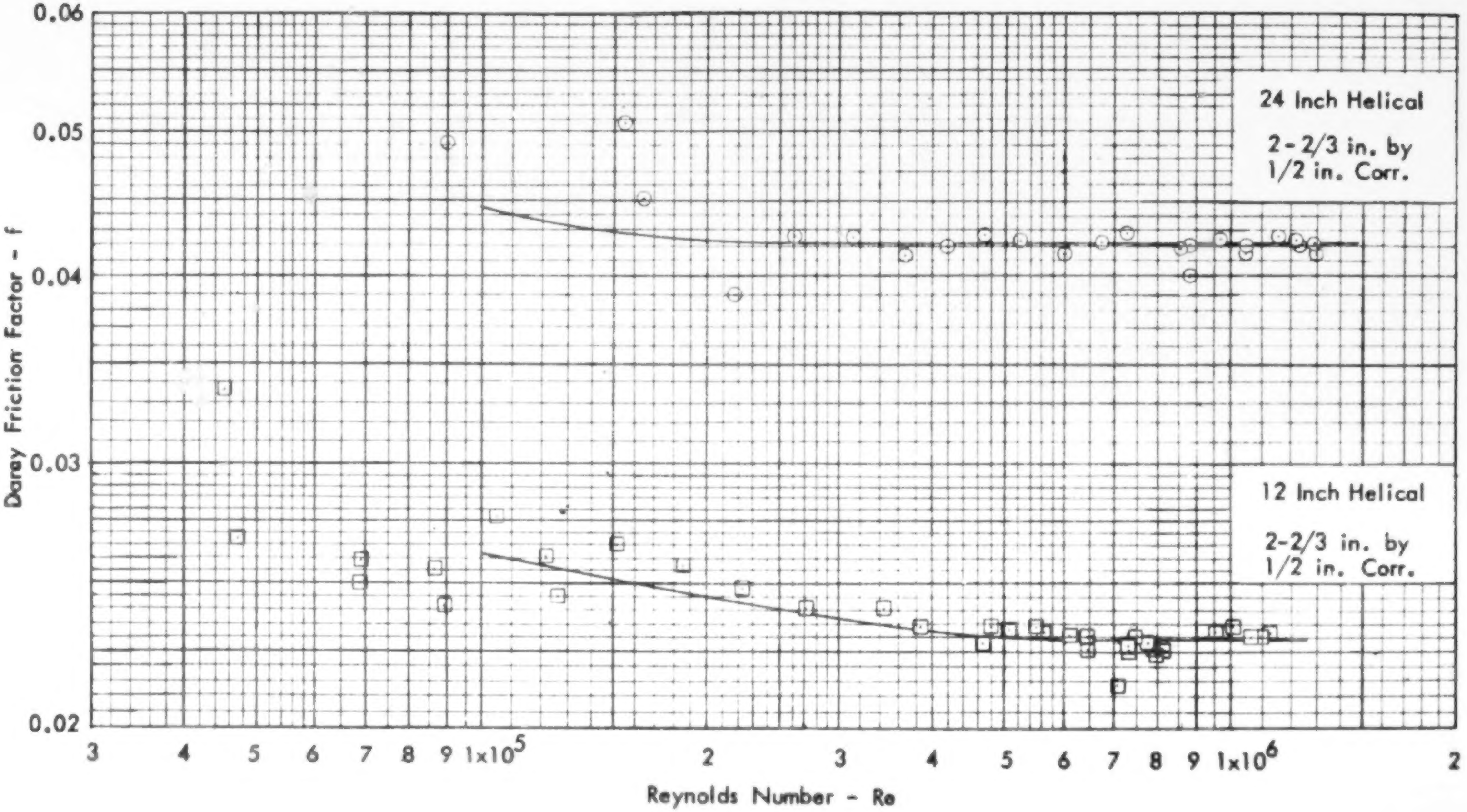


Fig. 23 - Variation of Darcy Friction Factor f with Reynolds Number - 12 Inch and 24 Inch Corrugated Pipe

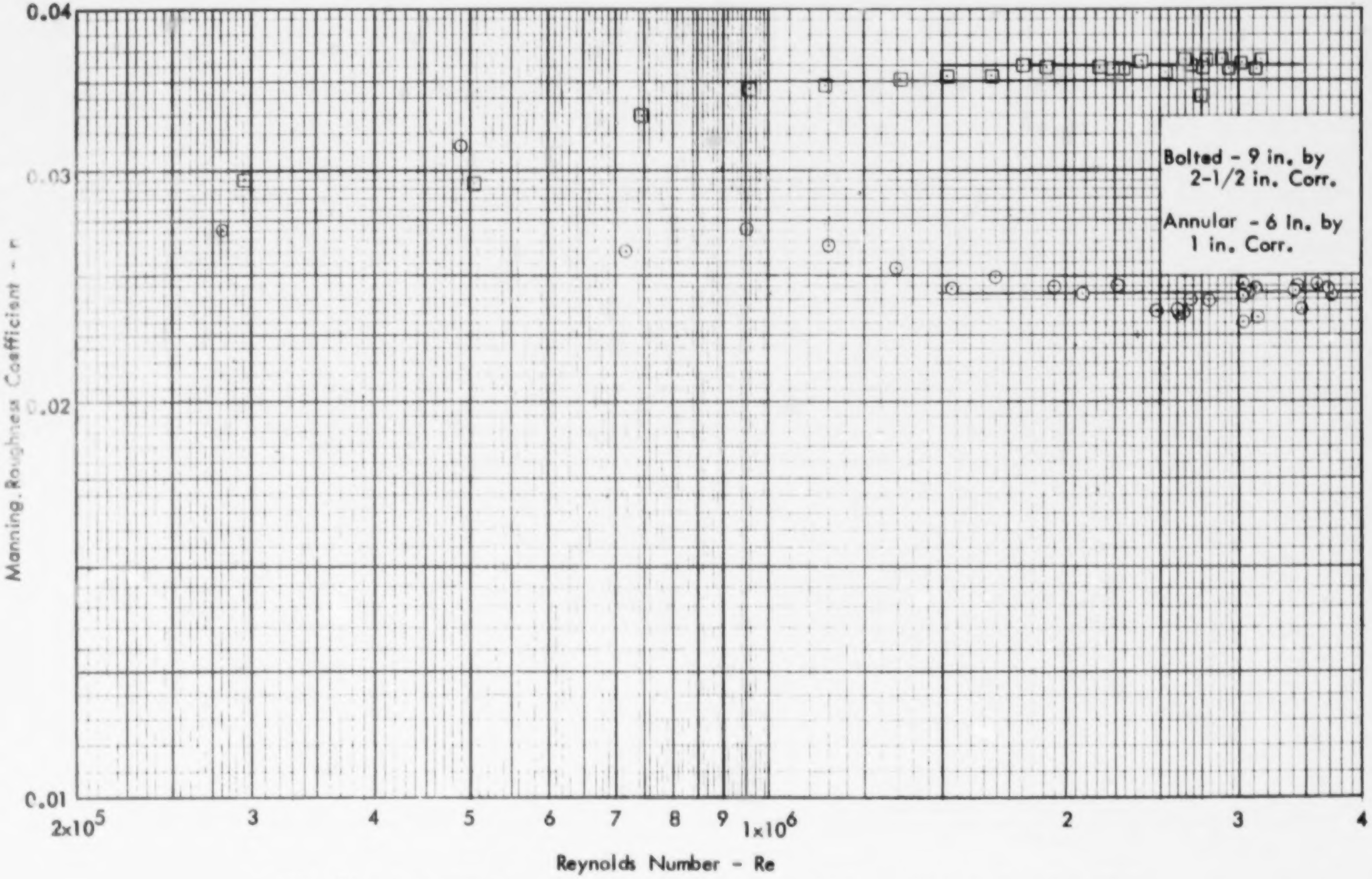


Fig. 24 - Variation of Manning n with Reynolds Number - 66 Inch Corrugated Pipe

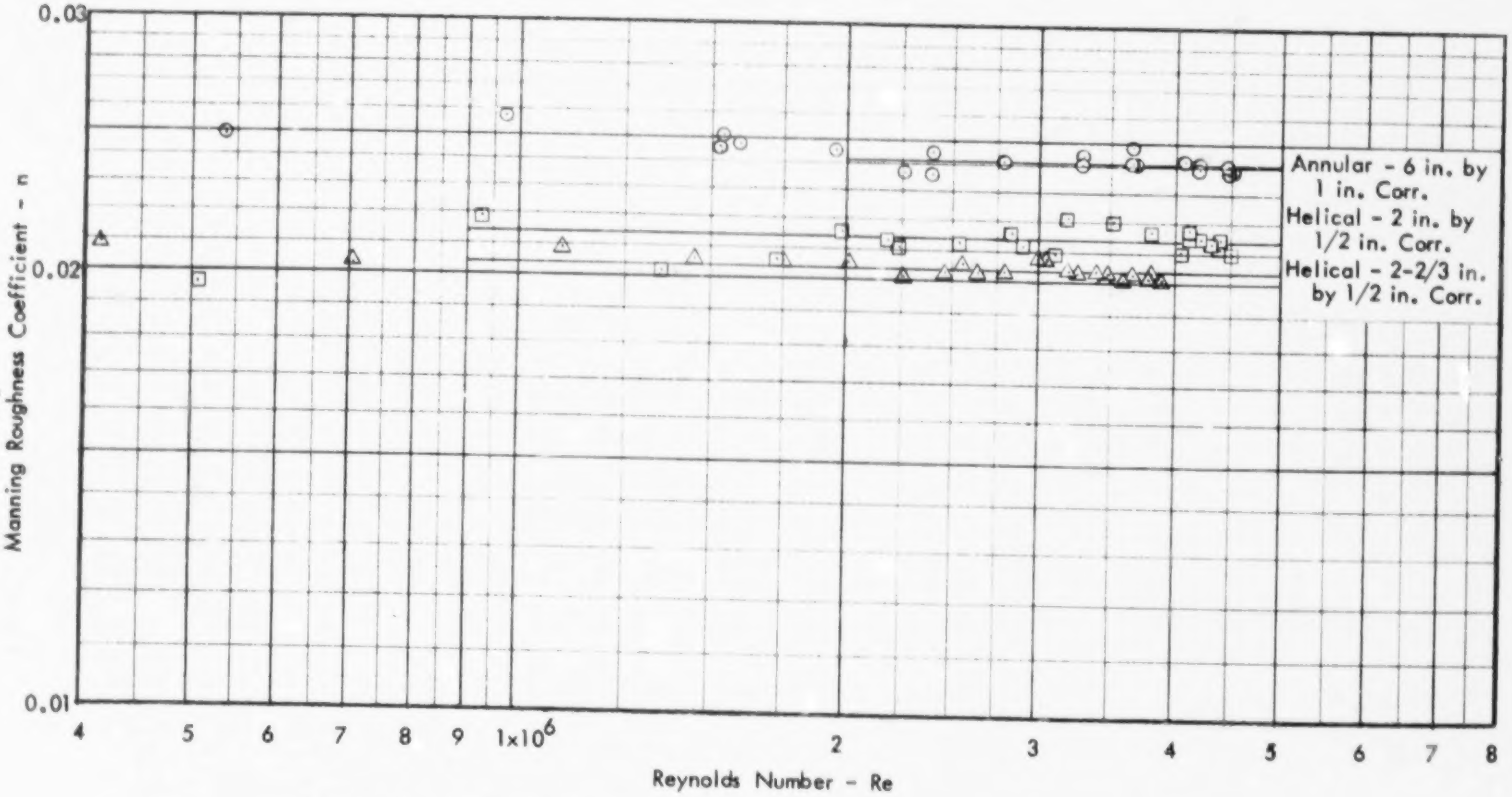


Fig. 25 - Variation of Manning n with Reynolds Number - 48 Inch Corrugated Pipe

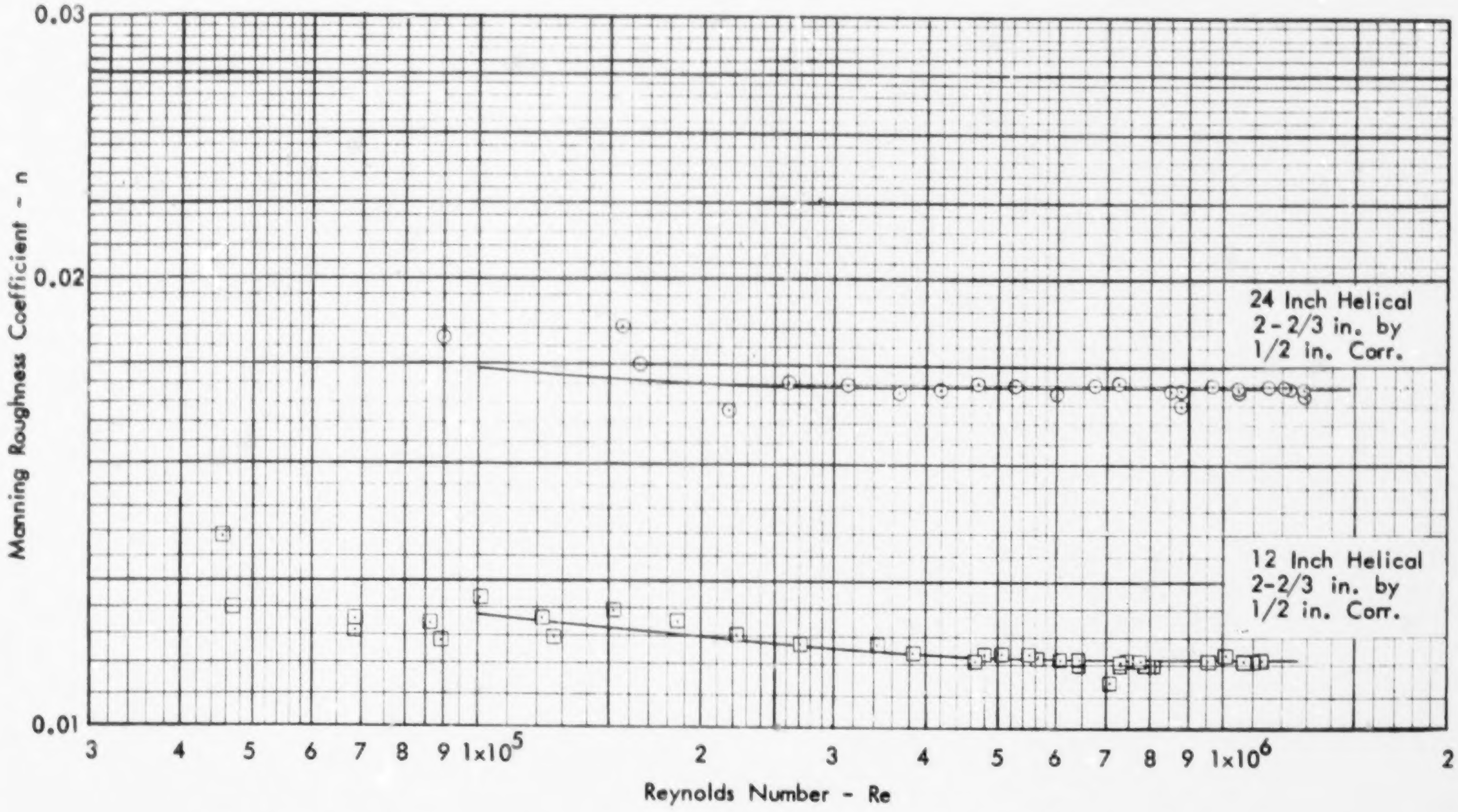


Fig. 26 - Variation of Manning n with Reynolds Number - 12 Inch and 24 Inch Corrugated Pipe

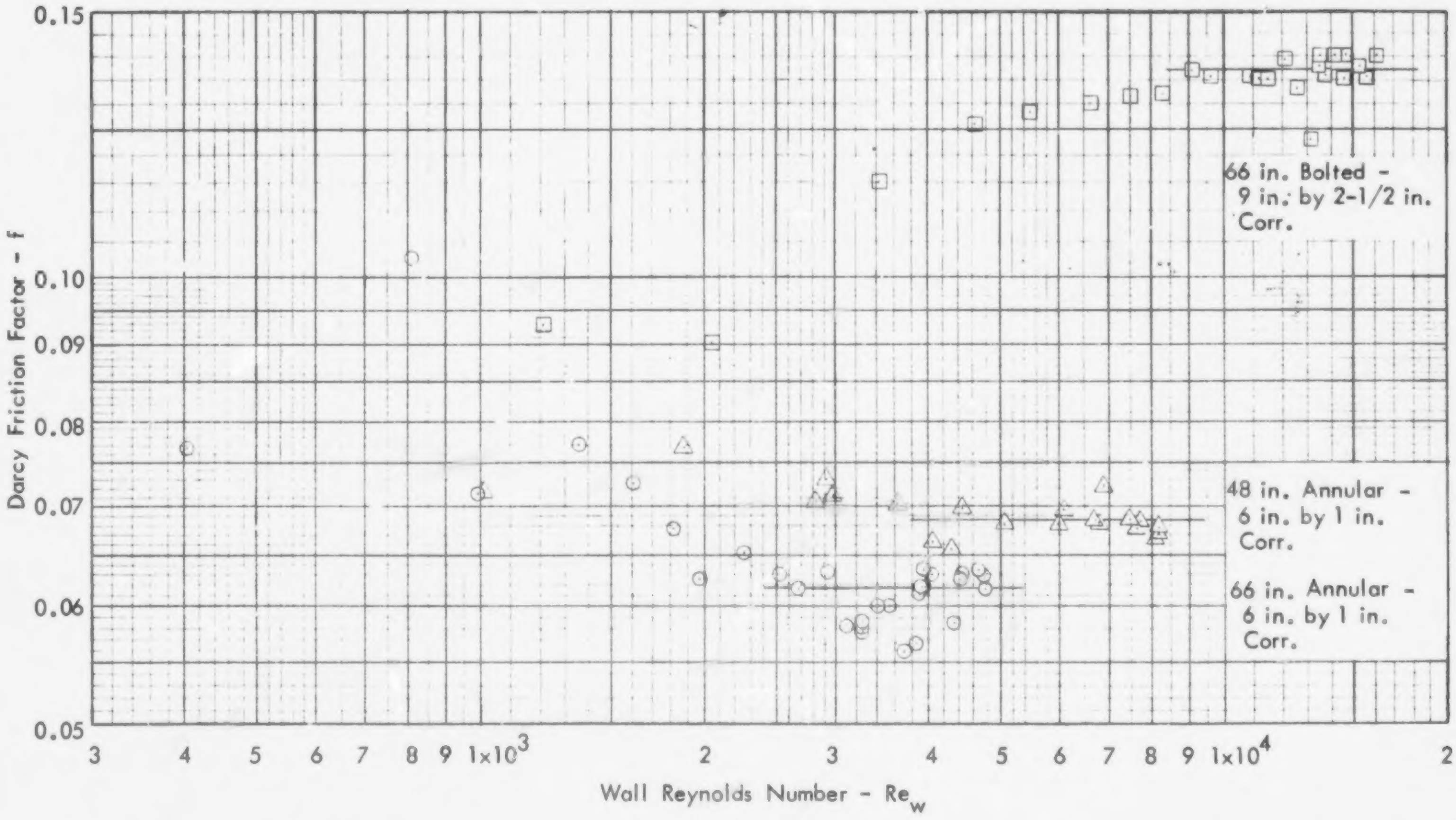


Fig. 27 - Variation of Darcy Friction Factor f with Wall Reynolds Number - Annular Corrugated Pipe

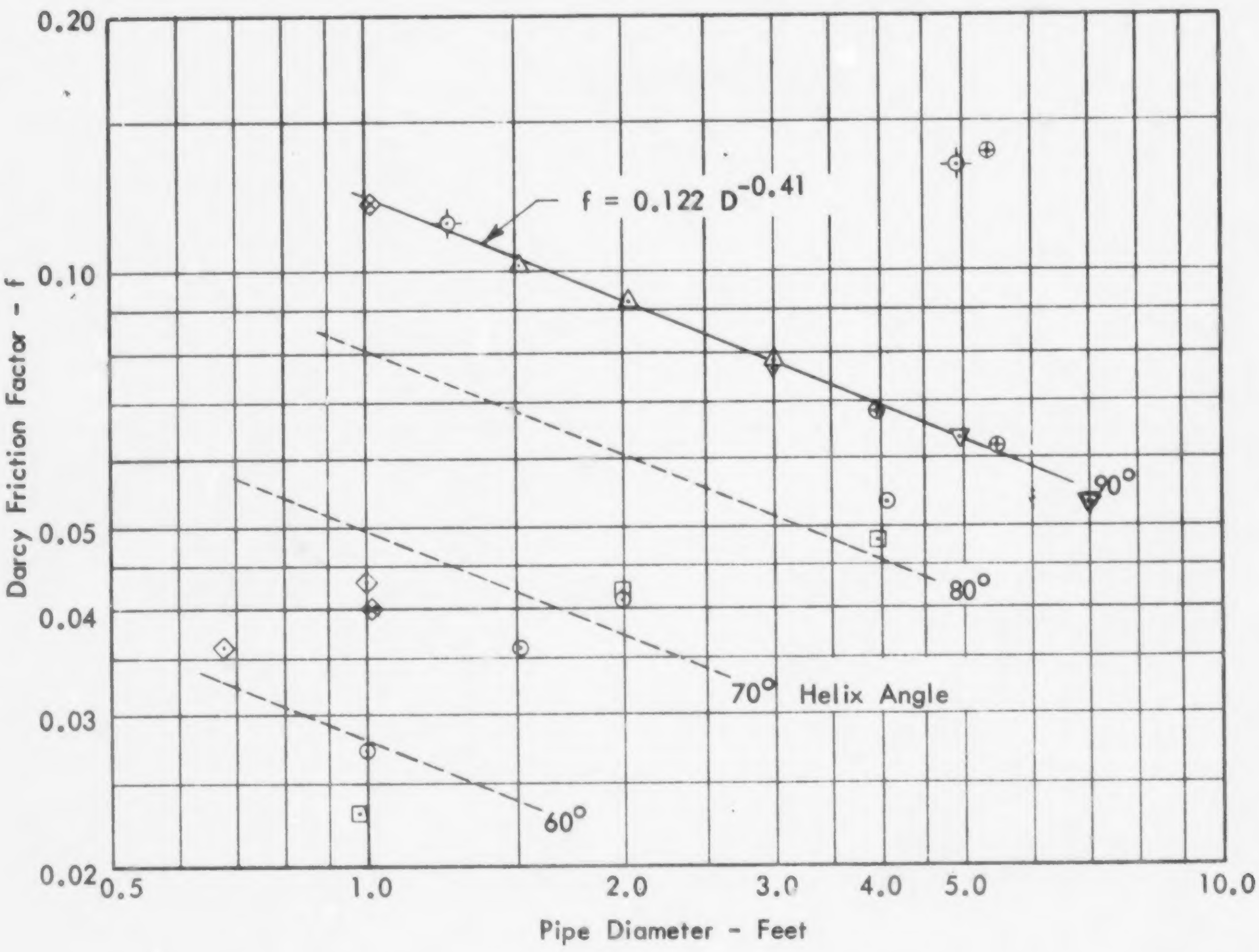


Fig. 28 - Darcy Friction Factor f as a Function of Pipe Diameter at High Reynolds Numbers

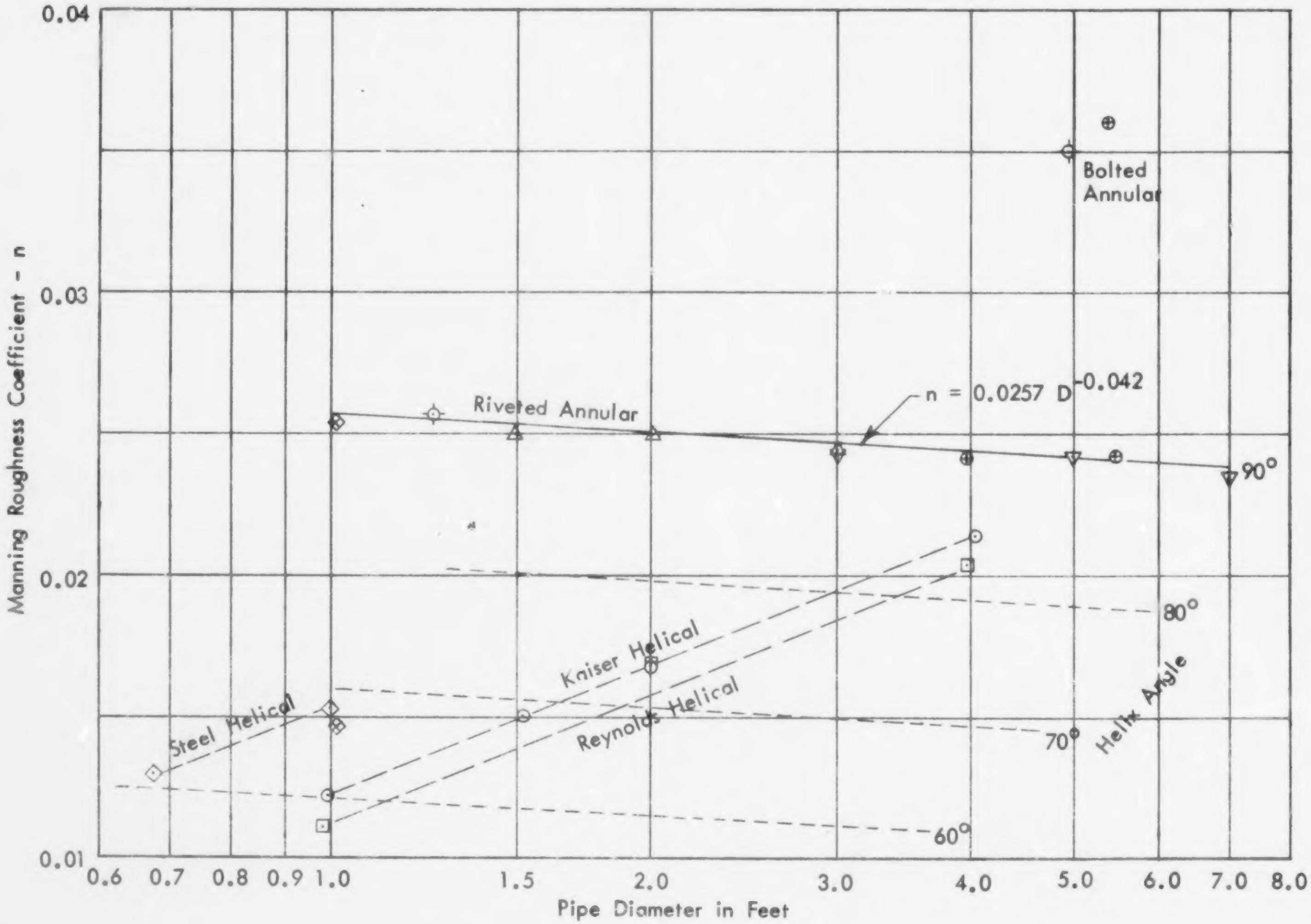


Fig. 29 - Manning Roughness Coefficient n as a Function of Pipe Diameter at High Reynolds Numbers

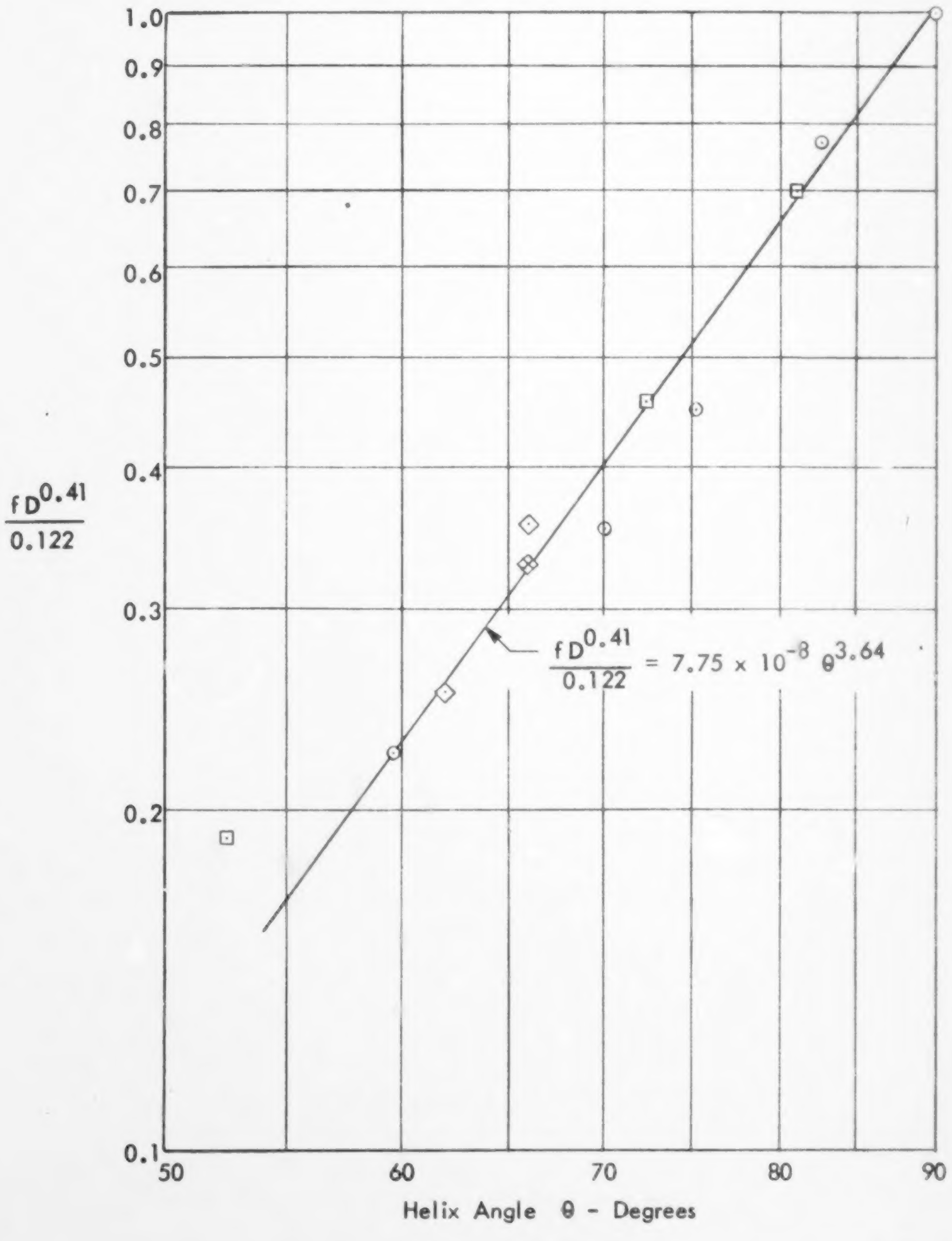


Fig. 30 - Friction Factor as a Function of Helix Angle at High Reynolds Numbers

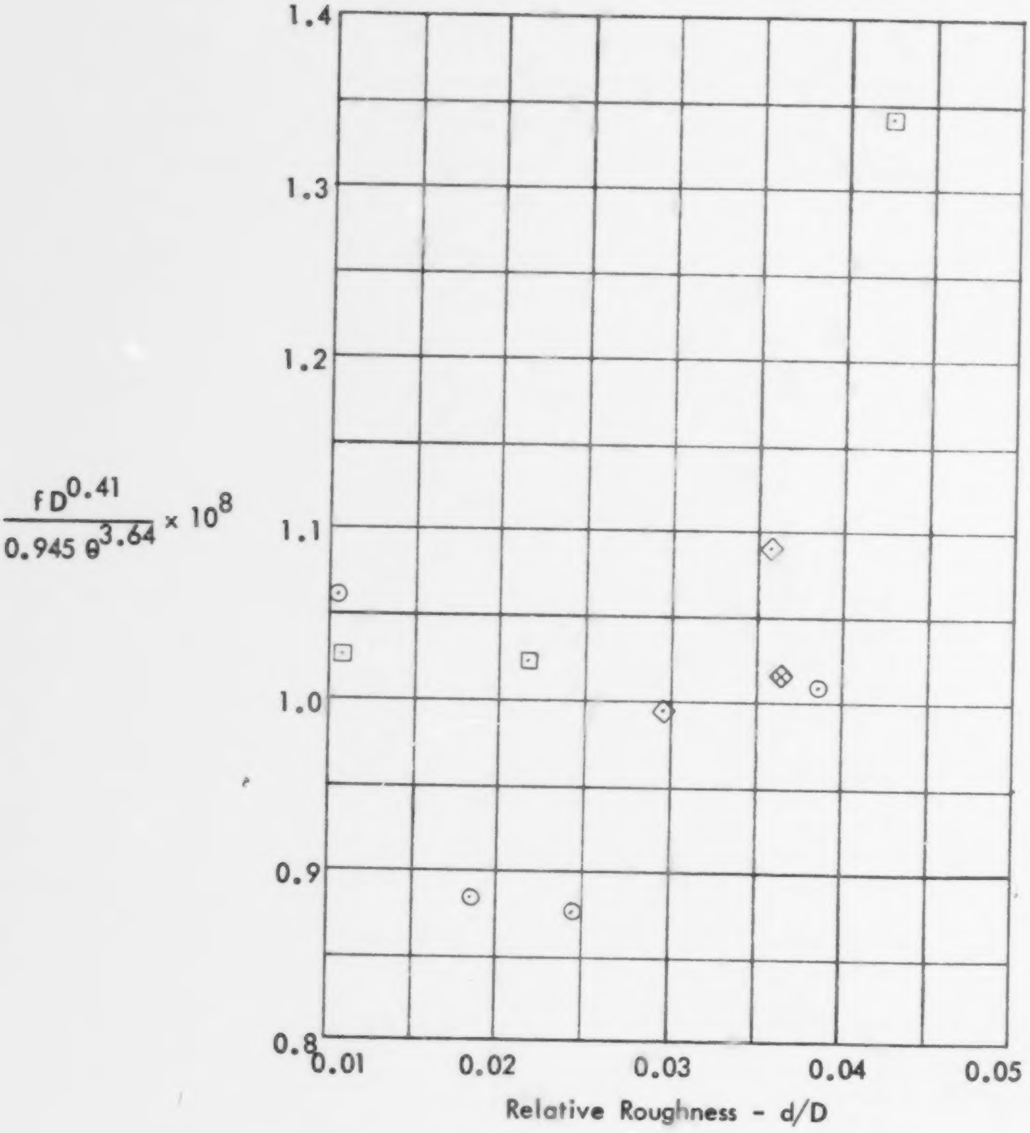


Fig. 31 - Friction Factor as a Function of Relative Roughness for Helical Pipes at High Reynolds Numbers

Appendix A

POSITION OF HYDRAULIC GRADE LINE AT THE PIPE OUTLET

Following the test runs in the main channel on the larger pipes with raised tailwater and on the smaller pipes with the downstream valve in place, test runs were made with the tailwater control gate down in the main channel and the downstream valve removed from the smaller pipes. In this manner the maximum discharge was obtained, along with several lower flows, by controlling the inflow at the upstream end. The procedure described earlier was used to measure the discharge, hydraulic grade lines, and water temperature. Typical hydraulic grade lines for the seven pipes tested are shown in Figs. A-1 through A-7 in actual relationship to the test pipe.

The friction factors computed from these data are consistent with the results found with raised tailwater or with the valve in place and are included in Tables I through VII as well as in the graphs of Figs. 21 through 27.

Also computed from these data were the values of y/D and $Q/D^{5/2}$, where y is the vertical distance between the pipe invert and the hydraulic grade line at the end of the pipe. These values are presented in Table A-1 and are plotted in Fig. A-8 along with the results presented in the authors' earlier study [1]. In Fig. A-8, the line drawn through the data points represents the results reported in the earlier study. The plots of data points for all pipes appear reasonable with the noticeable exception of the 12 in. helical pipe with 2-2/3 in. by 1/2 in. corrugations. The point with values of 0.735 for y/D and 5.22 for $Q/D^{5/2}$ plots near the curve drawn through the earlier data, but then with increasing values of $Q/D^{5/2}$, y/D changes from a decreasing to an increasing characteristic. A second series of tests was run to verify this at a later date, and similar results were obtained. Without further detailed study it is difficult to explain this phenomenon, although it might be attributable to the stronger rotations associated with the helix angle, which is 52-1/2 degrees for the 12 in. pipe tested currently and 59-1/2 degrees for the 12 in. pipe tested earlier.

TABLE A-1. POSITION OF HYDRAULIC GRADE LINE AT THE PIPE OUTLET

Q cfs	D ft	y ft	y/D	$Q/D^{5/2}$ $ft^{1/2}/sec$
66 in. Annular Riveted Pipe with 6 in. by 1 in. Corrugations				
302.81	5.4517	3.820	0.701	4.36
282.78	5.4517	3.970	0.728	4.07
277.94	5.4517	3.967	0.728	4.00
253.31	5.4517	4.134	0.758	3.65
249.92	5.4517	4.058	0.744	3.60
246.45	5.4517	4.102	0.753	3.55
246.04	5.4517	3.985	0.731	3.55
245.84	5.4517	4.080	0.748	3.54
212.75	5.4517	4.103	0.753	3.07
66 in. Annular Bolted Pipe with 9 in. by 2-1/2 in. Corrugations				
246.09	5.3808	3.910	0.727	3.66
219.66	5.3808	3.852	0.716	3.27
216.95	5.3808	3.948	0.734	3.23
208.49	5.3808	3.858	0.717	3.10
198.94	5.3808	[illegible].93[illegible]	0.732	2.96
180.50	5.3808	[illegible]06	0.707	2.69
48 in. Annular Riveted Pi[illegible]h 6 in. by 1 in. Corrugations				
181.73	3.9683	1.419	0.358	5.79
147.15	3.9683	2.519	0.635	4.69
147.14	3.9683	2.531	0.638	4.69
91.37	3.9683	3.040	0.766	2.91
48 in. Helical Lock Seam Pipe with 2 in. by 1/2 in. Corrugations				
189.74	4.0392	2.583	0.640	5.79
185.17	4.0392	2.684	0.664	5.65
178.12	4.0392	2.716	0.672	5.43
171.01	4.0392	2.875	0.712	5.21
48 in. Helical Lock Seam Pipe with 2-2/3 in. by 1/2 in. Corrugations				
193.90	3.9760	2.013	0.506	6.15
189.40	3.9760	2.097	0.528	6.01
184.89	3.9760	2.115	0.532	5.87
178.02	3.9760	2.305	0.580	5.65
174.57	3.9760	2.518	0.633	5.54
169.24	3.9760	2.607	0.656	5.37
163.89	3.9760	2.673	0.672	5.20

TABLE A-1. [Continued]

Q cfs	D ft	y ft	y/D	$Q/D^{5/2}$ $ft^{1/2}/sec$
24 in. Helical Lock Seam Pipe with 2-2/3 in. by 1/2 in. Corrugations				
38.417	1.9950	0.904	0.453	6.83
36.425	1.9950	0.993	0.498	6.48
31.311	1.9950	1.288	0.646	5.57
26.102	1.9950	1.505	0.754	4.64
19.982	1.9950	1.718	0.861	3.55
12 in. Helical Lock Seam Pipe with 2-2/3 in. by 1/2 in. Corrugations				
11.662	0.9781	0.843	0.862	12.33
10.454	0.9781	0.785	0.803	11.05
9.193	0.9781	0.685	0.700	9.72
7.246	0.9781	0.645	0.660	7.66
4.937	0.9781	0.719	0.735	5.22

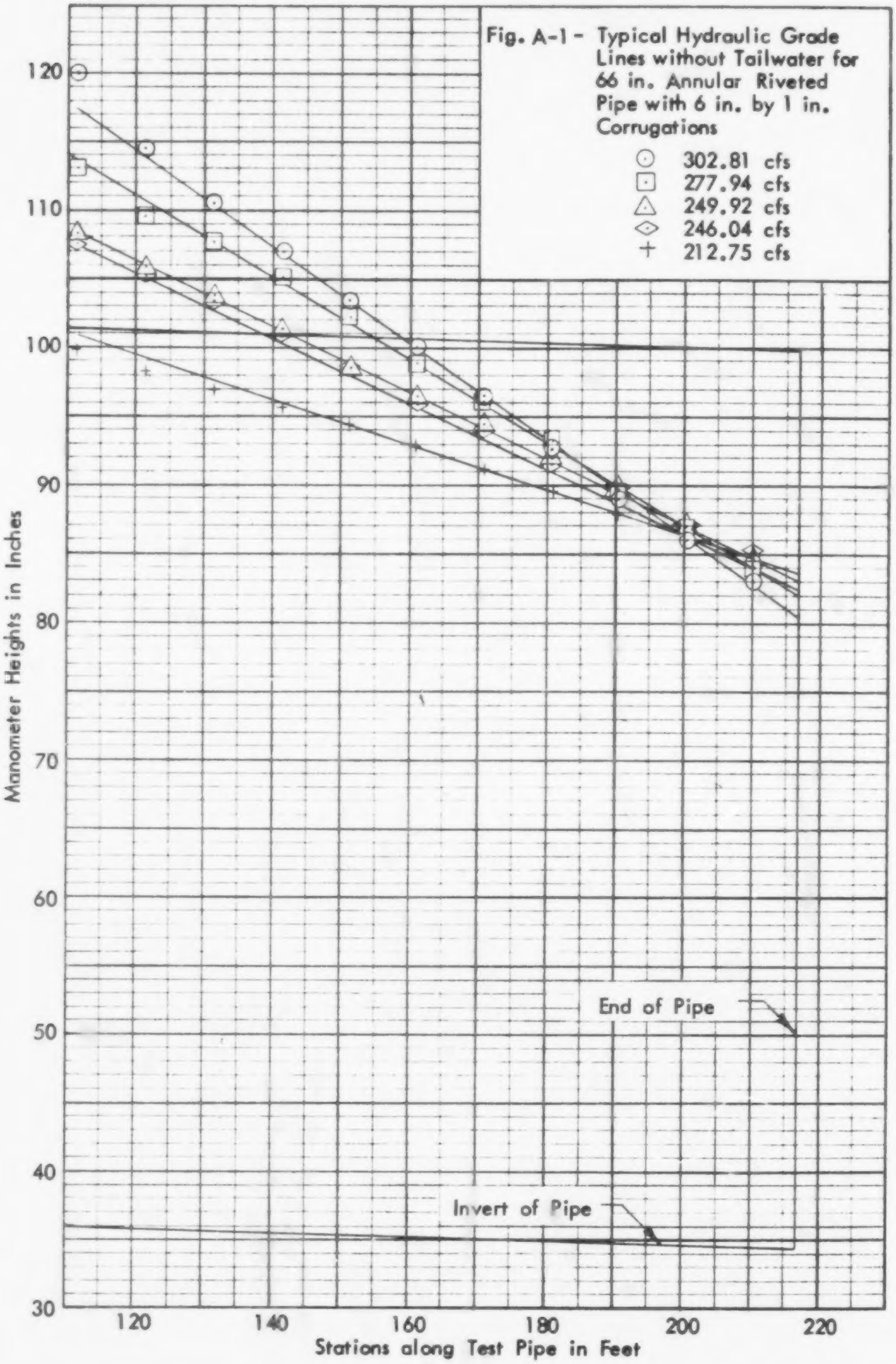


Fig. A-1 - Typical Hydraulic Grade Lines without Tailwater for 66 in. Annular Riveted Pipe with 6 in. by 1 in. Corrugations

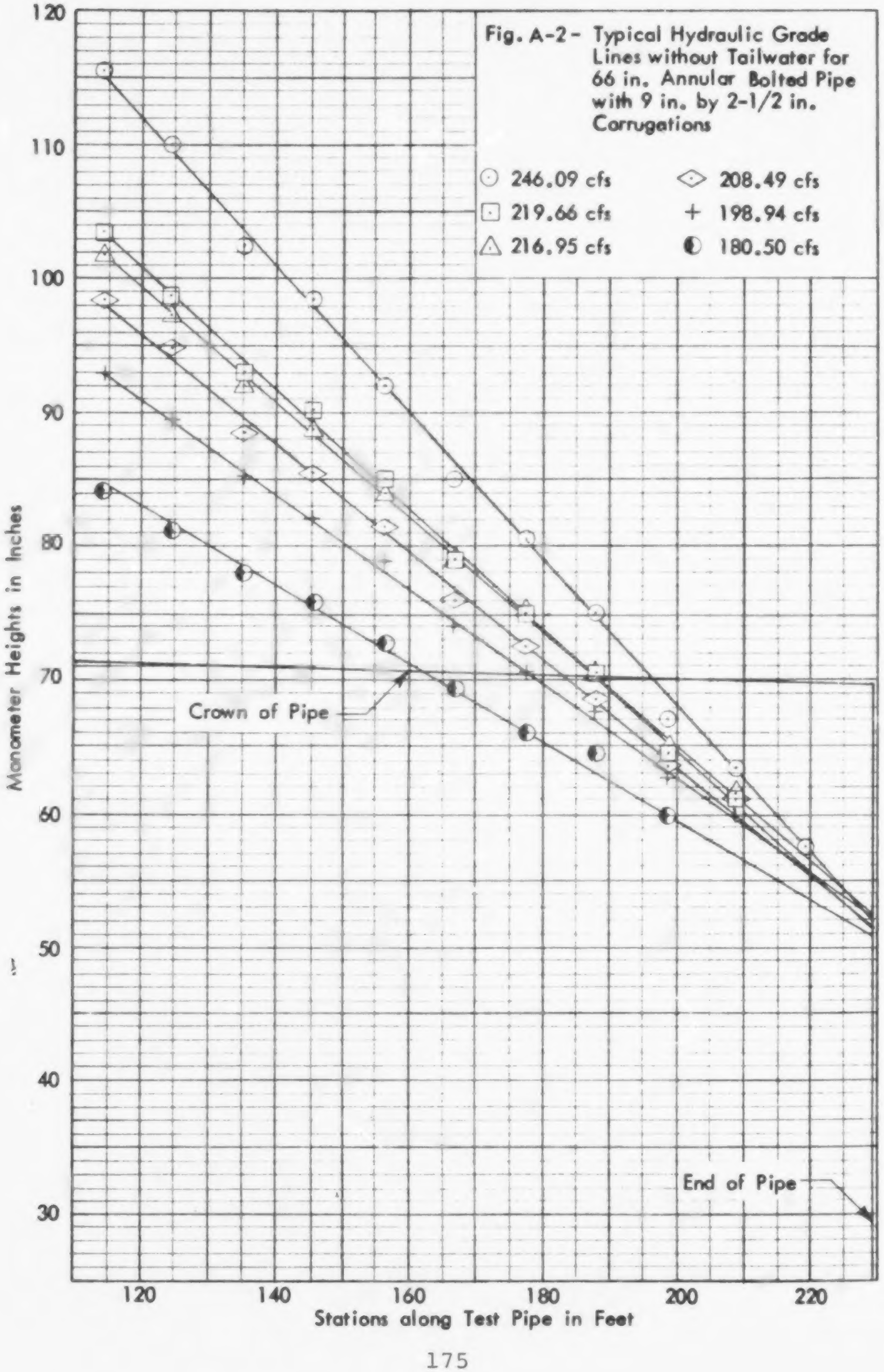


Fig. A-2- Typical Hydraulic Grade Lines without Tailwater for 66 in. Annular Bolted Pipe with 9 in. by 2-1/2 in. Corrugations

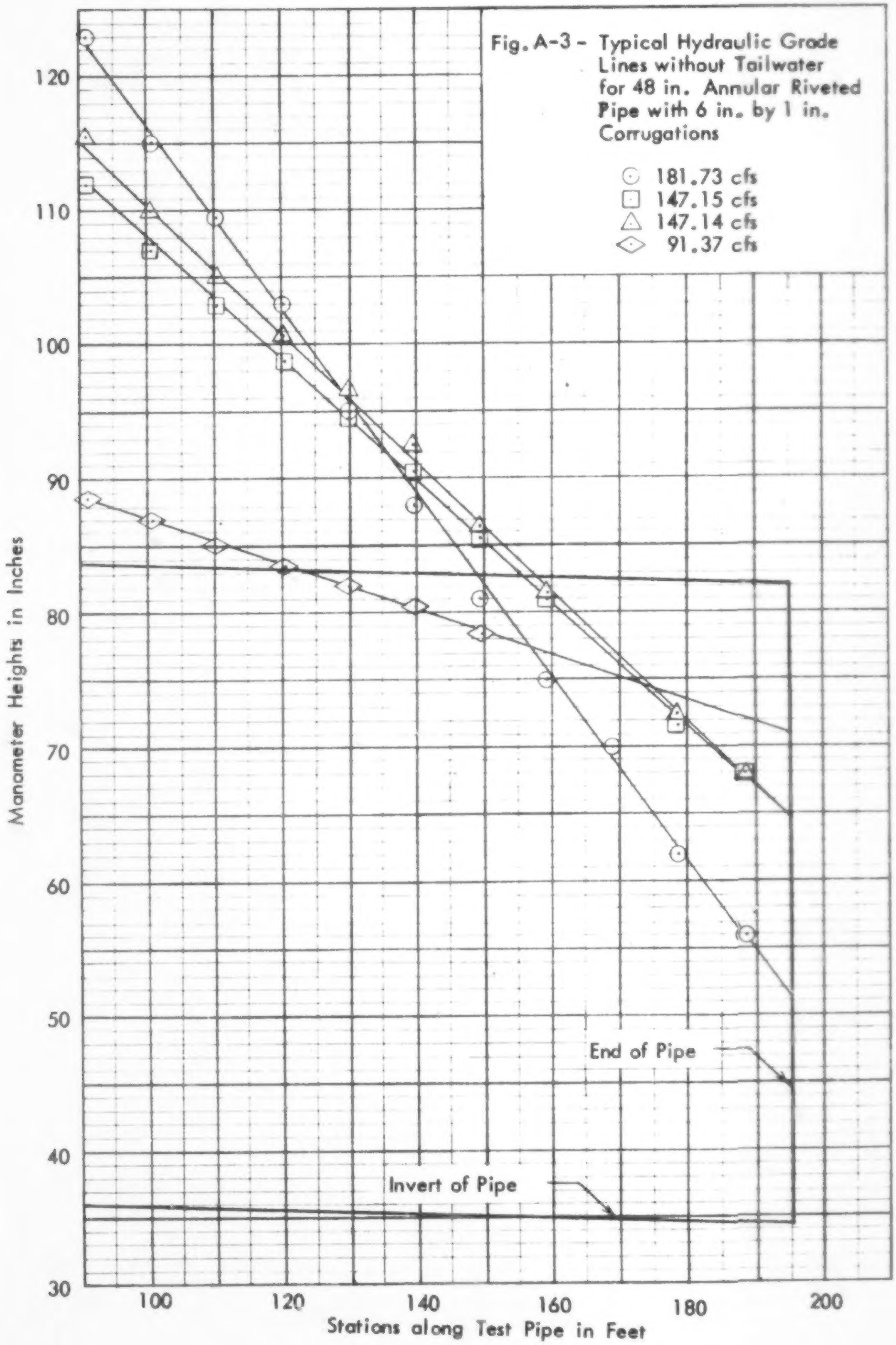


Fig. A-3 - Typical Hydraulic Grade Lines without Tailwater for 48 in. Annular Riveted Pipe with 6 in. by 1 in. Corrugations

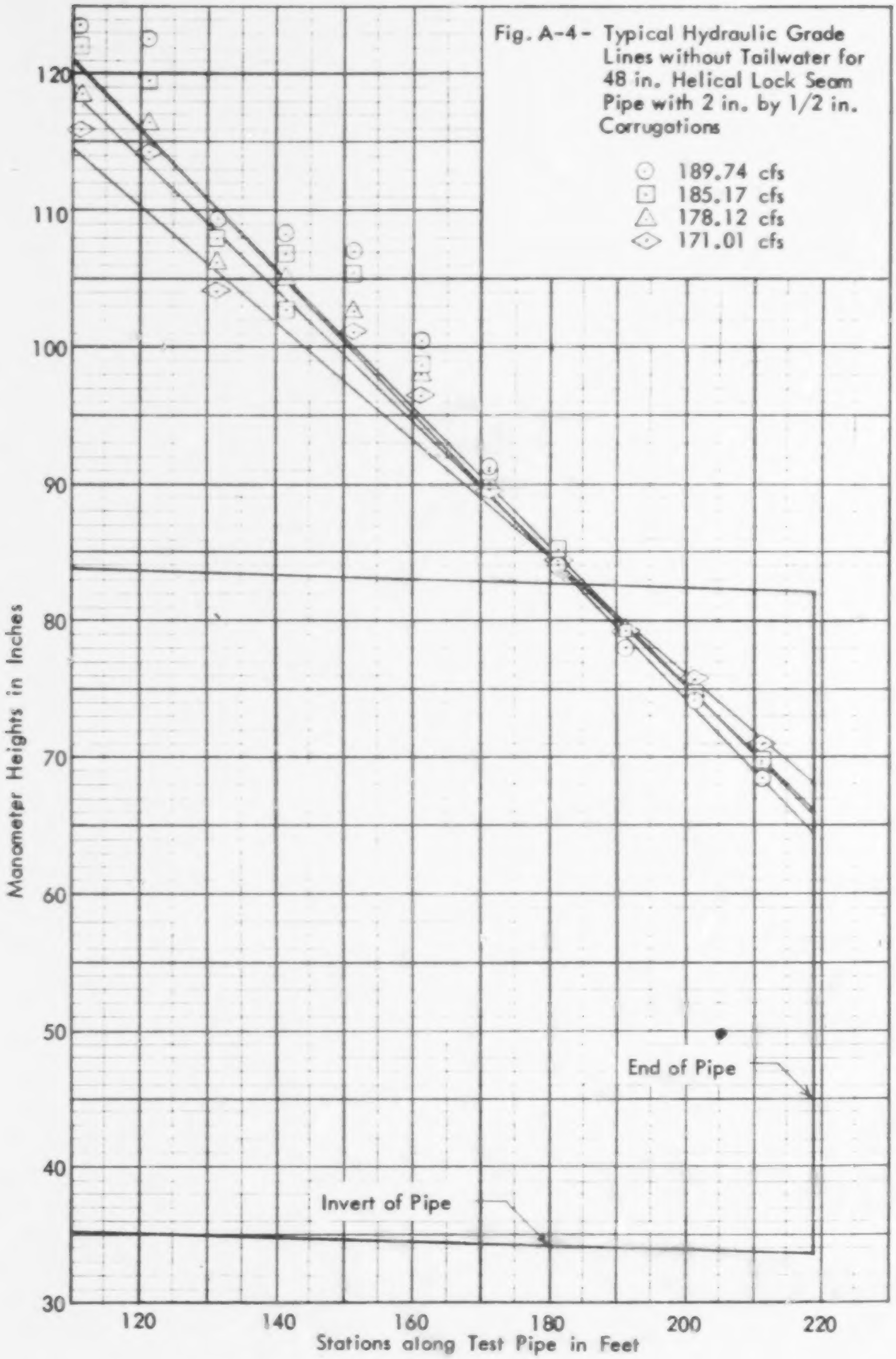


Fig. A-4 - Typical Hydraulic Grade Lines without Tailwater for 48 in. Helical Lock Seam Pipe with 2 in. by 1/2 in. Corrugations

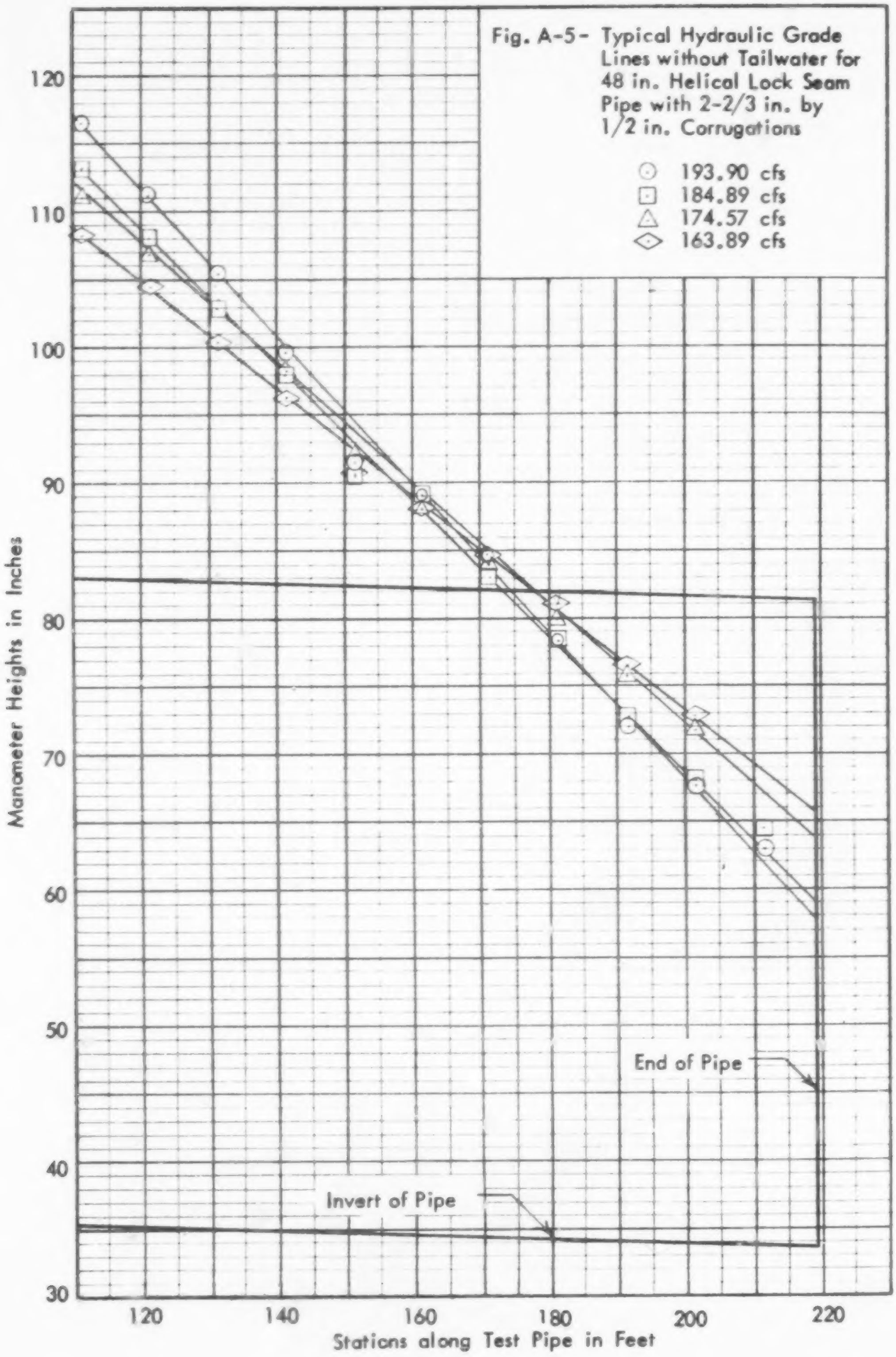


Fig. A-5- Typical Hydraulic Grade Lines without Tailwater for 48 in. Helical Lock Seam Pipe with 2-2/3 in. by 1/2 in. Corrugations

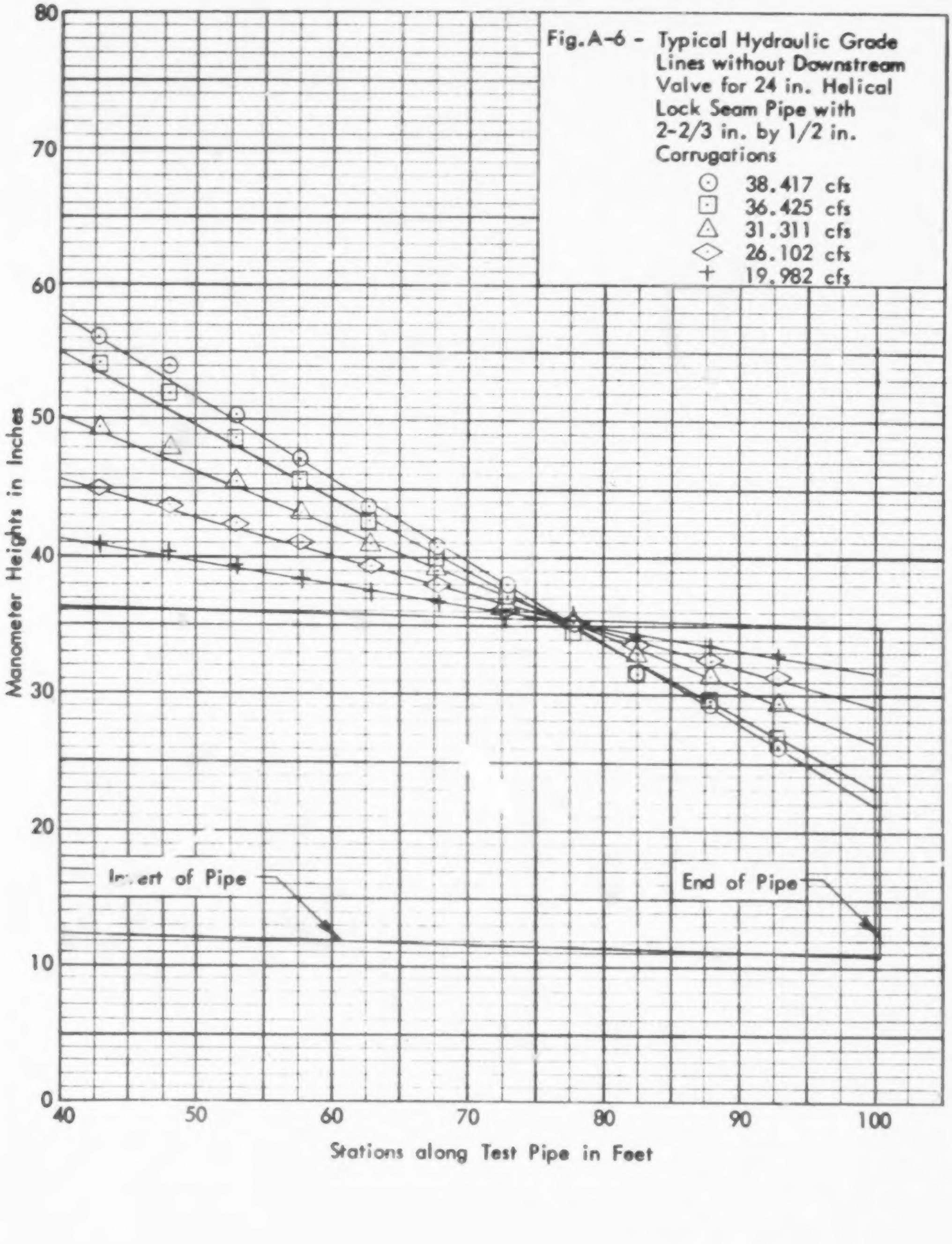


Fig. A-6 - Typical Hydraulic Grade Lines without Downstream Valve for 24 in. Helical Lock Seam Pipe with 2-2/3 in. by 1/2 in. Corrugations
⊙ 38.417 cfs
⊡ 36.425 cfs
△ 31.311 cfs
◇ 26.102 cfs
+ 19.982 cfs
Manometer Heights in Inches
Stations along Test Pipe in Feet
0
10
20
30
40
50
60
70
80
40
50
60
70
80
90
100
Invert of Pipe
End of Pipe

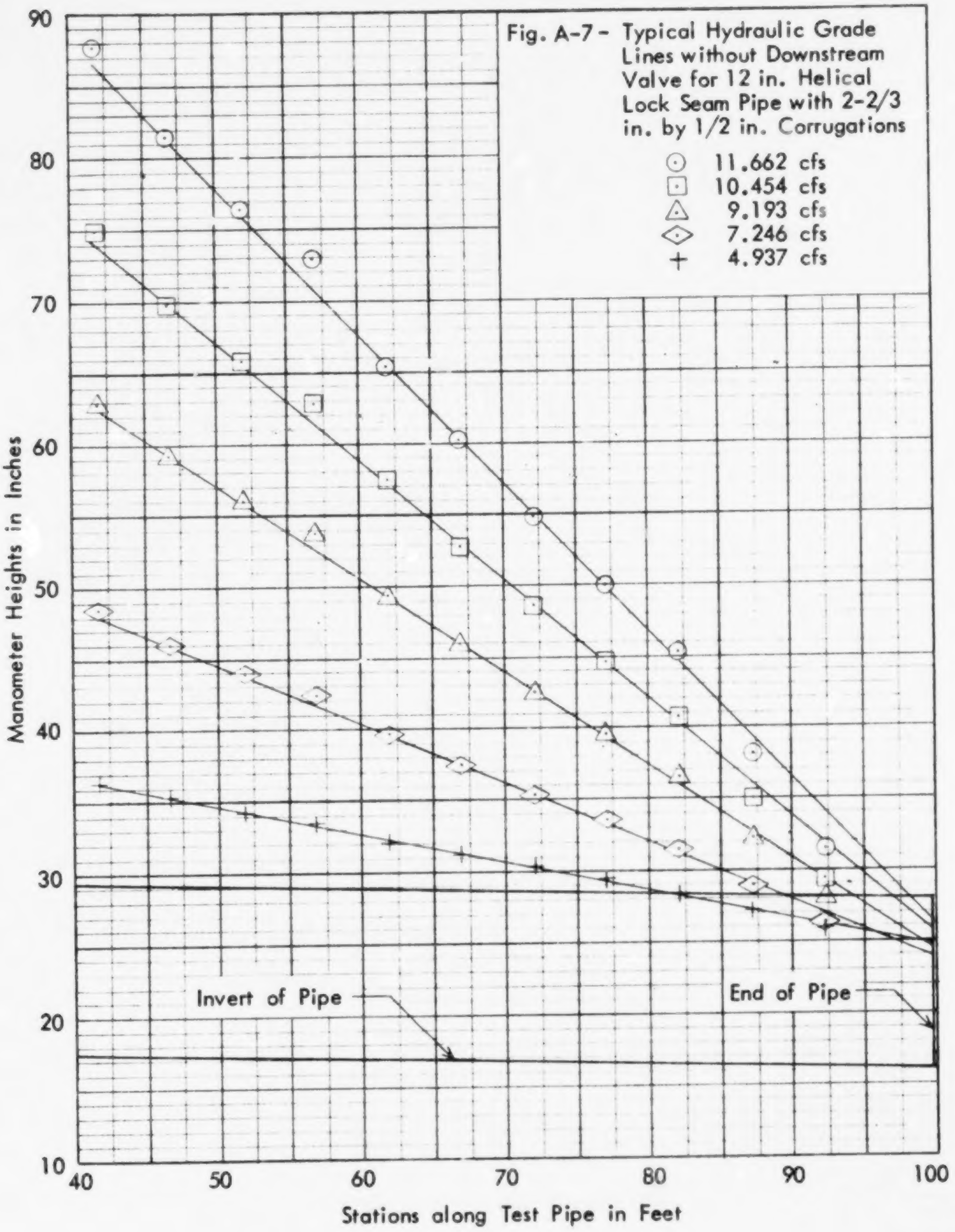
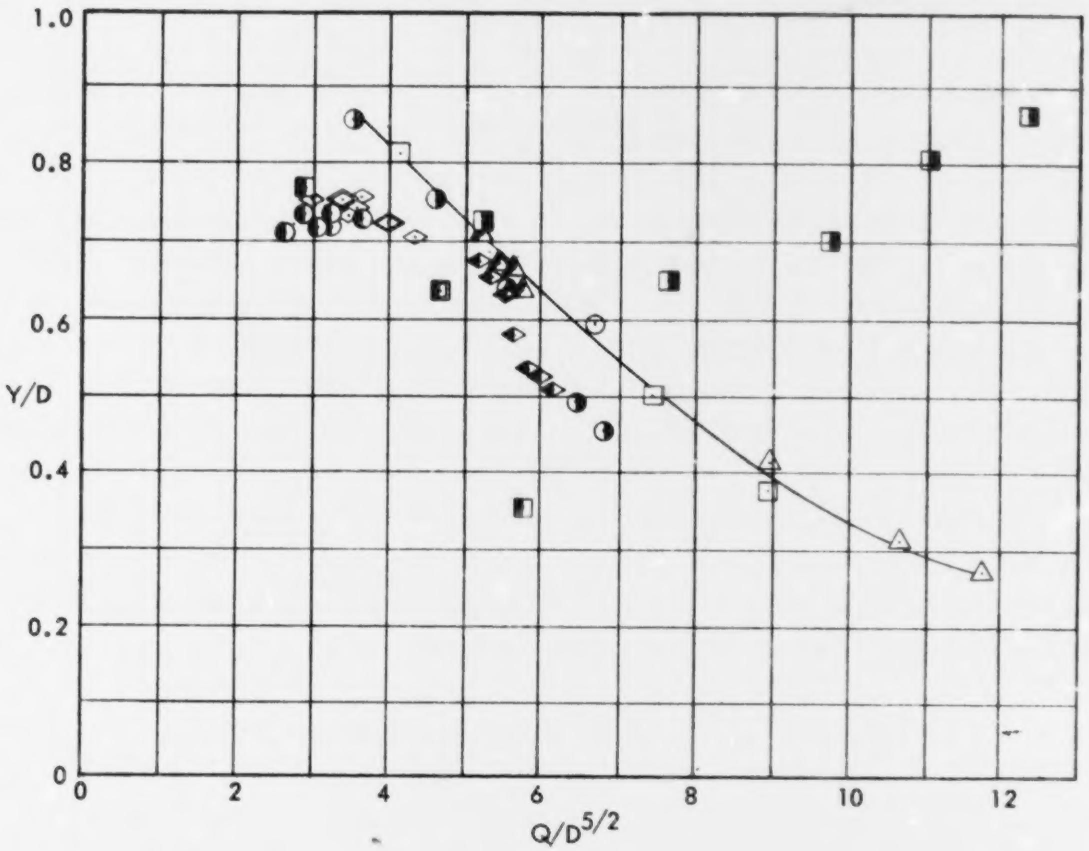


Fig. A-7 - Typical Hydraulic Grade Lines without Downstream Valve for 12 in. Helical Lock Seam Pipe with 2-2/3 in. by 1/2 in. Corrugations



	Type of Pipe	Pipe Dia. in.	Corrugations in.	
⊙	Helical	24	2 × 1/2	1969 Study
⊡	Helical	18	2 × 1/2	
△	Helical	12	2 × 1/2	
◇	Annular Riveted	66	6 × 1	This Work
◐	Annular Bolted	66	9 × 2-1/2	
◧	Annular Riveted	48	6 × 1	
▲	Helical	48	2 × 1/2	
◆	Helical	48	2-2/3 × 1/2	
◑	Helical	24	2-2/3 × 1/2	
◨	Helical	12	2-2/3 × 1/2	

These tests were made with no tailwater.

Fig. A-8 - Position of Hydraulic Grade Line at the Pipe Outlet

Appendix B

VELOCITY PROFILES

Velocity profiles were obtained along the vertical diameter at 10 ft from the end for the 24 in. and 12 in. pipes. The velocity direction and magnitude were measured with a 3/8 in. diameter pitot cylinder [2] used in conjunction with a static tube. The location of these measurements was shown in Fig. 7. As the flow is not parallel to the pipe axis, the static probe had to be directed into the flow. To accomplish this, the direction of flow was determined first with the pitot cylinder at a distance of 2.13 in. from the top and bottom of the pipe, this being the distance the static tube protruded into the pipe. The direction of the static tube was set to the average of these two directions. The tube reading served as a reference against which to measure total heads with the pitot cylinder. Traverses of the static tube from the 2.13 in. position toward the wall with the pitot cylinder held at a fixed position as reference showed that there was practically no static pressure variation over this distance.

Velocity profiles were obtained for the following runs:

RUNS FOR WHICH VELOCITY PROFILES WERE OBTAINED

Pipe size in.	Q Meas. cfs	D ft	$\overline{V}$ fps	$\nu \times 10^5$ ft^2/sec	Re $\times 10^{-6}$	f (Fig. 23)	Q Integrated cfs
24	26.198	1.9950	8.380	1.895	0.8822	0.0422	26.10
12	8.258	0.9781	10.990	1.859	0.5782	0.0229	8.35
12	8.148	0.9781	10.844	1.859	0.5705	0.0229	8.20

Tables B-1, B-2, and B-3 contain the basic measured data along with some computations based thereon. Figures B-1 and B-2 show the velocity magnitude plotted along the vertical diameter for the two pipes. Velocity readings above +11.90 inches in the 24 in. pipe (Fig. B-1) and above +5.85 inches in the 12 in. pipe (Fig. B-2) were measured within the corrugation at the top of the pipe.

Figure B-3 shows the velocity magnitude and direction in the top halves of the pipes. The center flow was axial for the 12 in. pipe and 2 degrees from axial in the 24 in. pipe, the latter direction being used as the reference or zero angle. Figure B-3 shows that close to the wall the flow approaches the helical direction and that in the corrugation it is essentially in the helical direction. The photographs in Fig. B-4 show the flow directions at the outlet for the two 48 in. pipes, one annular and the other helical. The spiral nature of the flow along the wall of a helical pipe is clearly shown by a comparison of the two photos.

The velocity profiles have been plotted in the form of the velocity defect law in Fig. B-5 and in law-of-the-wall form in Fig. B-6. For comparison, similar plots from the earlier work [1] have also been placed on these graphs. The results are quite comparable, although the new data indicate, from Fig. B-5, that the reduction in turbulence may not be quite so great for the new pipes as it was in the earlier tests. The reason for the slight difference is not readily apparent.

The law-of-the-wall plot in Fig. B-6 shows that the roughness of the 24 in. helical pipe in the present tests should be somewhat less than in the previous tests. This was not borne out by the friction factor measurements displayed in Figs. 28 and 29. Figure B-6 also seems to indicate that the present 12 in. pipe has about the same roughness as the previous 12 in. pipe of larger helix angle. Again, the friction factor measurements displayed in Figs. 28 and 29 show a different result, the smaller helix angle pipe showing a lesser friction factor. The discrepancies are not large, and certainly the direct measurements of friction factor should be given precedence.

TABLE B-1. VELOCITY PROFILE DATA FOR 24 IN. PIPE - 2-2/3 in. by 1/2 in. Corrugations

$\overline{V} = 8.38$ fps, $V_* = 0.61$ fps, $\nu = 1.90 \times 10^{-5}$ ft^2/sec

				TOP OF PIPE					BOTTOM OF PIPE				
Distance from pipe C_L, in.	Distance from outer wall y, ft	yV_*/ν x 10^{-4}	y/R	V fps	α, Deg.	U = V cos α fps	U/V_*	$\frac{U_{max} - U}{V_*}$	V fps	α, Deg.	U = V cos α fps	U/V_*	$\frac{U_{max} - U}{V_*}$
0.00	1.035	3.320	1.000	11.84	0.0	11.84	19.40	0.00	11.84	0.0	11.84	19.40	0.00
2.00	0.868	2.785	0.840	11.51	2.0	11.50	18.85	0.56	11.48	2.0	11.47	18.80	0.77
4.00	0.702	2.555	0.676	10.88	2.0	10.87	17.80	1.59	10.82	4.0	10.80	17.70	1.71
6.00	0.535	1.720	0.516	9.89	4.0	9.87	16.20	3.24	9.76	4.5	9.73	15.90	3.46
7.00	0.452	1.453	0.436	9.38	6.0	9.31	15.30	4.15	9.35	6.5	9.26	15.20	4.24
8.00	0.368	1.180	0.356	8.75	9.0	8.65	14.20	5.23	8.86	10.0	8.71	14.30	5.14
8.50	0.327	1.050	0.315	8.60	10.0	8.45	13.85	5.56	8.64	10.0	8.50	13.90	5.49
9.00	0.285	0.915	0.275	8.22	12.0	8.04	13.20	6.24	8.14	12.5	7.94	13.00	6.40
9.50	0.243	0.780	0.235	8.02	12.0	7.85	12.90	6.55	7.86	16.0	7.55	12.40	7.04
9.76	0.222	0.712	0.214	7.78	14.5	7.51	12.30	7.10	7.78	17.0	7.53	12.30	7.07
10.00	0.202	0.649	0.195	7.56	16.0	7.26	11.90	7.51	7.48	18.0	7.10	11.65	7.77
10.25	0.181	0.580	0.175	7.39	19.5	6.96	11.40	8.00	7.39	21.0	6.90	11.30	8.10
10.50	0.160	0.514	0.155	7.31	22.0	6.77	11.10	8.33	7.27	21.0	6.79	11.10	8.29
10.75	0.139	0.445	0.134	7.17	25.0	6.50	10.65	8.75	7.13	24.0	6.50	10.65	8.75
11.00	0.117	0.376	0.114	7.03	29.0	6.15	10.10	9.33	6.95	27.5	6.16	10.10	9.32
11.25	0.0975	0.313	0.094	6.85	31.0	5.86	9.60	9.81	6.71	29.0	5.86	9.60	9.81
11.50	0.077	0.247	0.074	6.51	34.5	5.36	8.80	10.62	6.51	30.0	5.64	9.25	10.13
11.60	0.068	0.218	0.066						6.42	32.0	5.45	8.94	10.48
11.70	0.060	0.193	0.058						6.31	33.0	5.30	8.70	10.72
11.75	0.056	0.180	0.054	6.16	40.0	[illegible]71	7.71	11.70					
11.80	0.052	0.167	0.050						5.88		5.19	8.50	10.90
12.00	0.035	0.112	0.034	5.61	52.0	3.46	5.66	13.72					
12.10	0.027	0.086	0.026	5.44	57.0	2.96	4.85	14.56					
12.20	0.018	0.058	0.018	5.44	65.5	2.25	3.69	15.70					
12.30	0.010	0.032	0.010	5.38	68.0	2.01	3.30	16.11					

TABLE B-2. VELOCITY PROFILE DATA FOR 12 IN. PIPE - RUN 1 - 2-2/3 in. by 1/2 in. Corrugations

$\overline{V}$ = 10.990 fps, V_* = 0.590 fps, $\nu = 1.859 \times 10^{-5}$ ft^2/sec

Distance from pipe C_L, in.	Distance from outer wall y, ft	yV_*/ν x 10^{-4}	y/R	TOP OF PIPE V fps	 α, Deg.	 U = V cos α fps	 U/V_*	 $\frac{U_{max}-U}{V_*}$	BOTTOM OF PIPE V fps	 α, Deg.	 U = V cos α fps	 U/V_*	 $\frac{U_{max}-U}{V_*}$
0.00	0.528	1.667	1.000	14.123	0.0	14.120	24.00	0.00	14.123	0.0	14.120	24.00	0.00
0.50	0.487	1.533	0.921	14.123	-1.0	14.120	24.00	0.00	14.147	1.0	14.150	24.00	0.00
1.00	0.445	1.402	0.842	14.003	-1.0	14.000	23.75	0.20	14.003	1.5	14.000	23.75	0.20
1.50	0.403	1.270	0.764	13.706	0.0	13.710	23.25	0.70	13.730	4.0	13.700	23.20	0.71
2.00	0.362	1.140	0.684	13.345	0.5	13.345	22.60	1.31	13.417	4.0	13.385	22.70	1.25
2.50	0.320	1.010	0.605	12.960	1.0	12.960	22.00	1.96	13.008	4.5	12.970	22.00	2.12
3.00	0.278	0.879	0.527	12.447	1.5	12.440	21.10	2.84	12.551	4.5	12.510	21.20	2.73
3.50	0.237	0.747	0.449	11.974	4.5	11.940	20.25	3.70	12.166	9.0	12.020	20.40	3.56
3.65	0.224	0.708	0.425	11.870	5.0	11.825	20.05	3.89	11.894	8.5	11.760	19.90	4.00
3.75	0.216	0.681	0.409	11.701	6.5	11.630	19.70	4.22	11.870	9.5	11.710	19.85	4.09
4.00	0.195	0.615	0.370	11.485	8.0	11.370	19.30	4.66	11.597	11.0	11.400	19.30	4.61
4.25	0.174	0.550	0.330	11.316	11.5	11.190	18.95	4.96	11.428	13.0	11.130	18.90	5.07
4.50	0.153	0.484	0.290	10.939	15.0	10.565	17.90	6.03	11.172	15.5	10.770	18.25	5.69
4.75	0.1325	0.419	0.251	10.819	19.0	10.230	17.40	6.60	10.963	18.5	10.430	17.70	6.25
5.00	0.112	0.352	0.222	10.667	22.0	9.890	16.75	7.16	10.763	20.0	10.110	17.15	6.80
5.25	0.091	0.287	0.172	10.458	24.5	9.520	16.15	7.80	10.514	22.0	9.750	16.50	7.41
5.50	0.070	0.221	0.133	10.298	28.0	9.090	15.40	8.52	10.209	24.0	9.320	15.80	8.14
5.60	0.062	0.194	0.117						10.081	26.5	9.020	15.30	8.65
5.70	0.053	0.168	0.101						9.921	27.0	8.840	15.00	8.95
5.75	0.049	0.155	0.093	9.985	31.5	8.510	14.40	9.52					
5.80	0.045	0.142	0.085						9.688	23.0	8.820	14.95	8.99
5.85	0.041	0.129	0.077	9.592	33.5	7.840	13.30	10.63					
5.95	0.0325	0.1025	0.062	9.351	40.0	6.880	11.65	12.27					
6.05	0.024	0.0763	0.046	9.319	44.5	6.650	11.30	12.66					
6.15	0.016	0.050	0.030	9.215	48.0	6.160	10.45	13.50					
6.25	0.0075	0.0236	0.014	9.215	~~48.0~~	~~6.160~~	10.45	13.50					

TABLE B-3. VELOCITY PROFILE DATA FOR 12 IN. PIPE - RUN 2 - 2-2/3 in. by 1/2 in. Corrugations

$\bar{V} = 10.844$ fps, $V_* = 0.584$ fps, $\nu = 1.859 \times 10^{-5}$ ft^2/sec

Distance from pipe C_L, in.	Distance from outer wall y, ft	yV_*/ν x 10^{-4}	y/R	TOP OF PIPE V fps	 α, Deg.	 U = V cos α fps	 U/V_*	 $\frac{U_{max}-U}{V_*}$	BOTTOM OF PIPE V fps	 α, Deg.	 U = V cos α fps	 U/V_*	 $\frac{U_{max}-U}{V_*}$
0.00	0.528	1.655	1.000	13.891	0.0	13.891	23.80	0.00	13.891	0.0	13.891	23.80	0.00
0.50	0.487	1.530	0.921	13.843	0.5	13.843	23.80	0.08	13.778	-1.0	13.775	23.60	0.20
1.00	0.445	1.400	0.842	13.730	1.5	13.726	23.55	0.28	13.634	0.5	13.634	22.40	0.44
1.50	0.403	1.265	0.764	13.538	1.5	13.534	23.25	0.61	13.442	0.5	13.442	23.10	0.77
2.00	0.362	1.135	0.684	13.249	3.0	13.230	22.70	1.13	13.105	0.5	13.105	22.50	1.35
2.50	0.320	1.003	0.605	12.880	3.0	12.862	22.05	1.72	12.728	1.0	12.725	21.85	2.00
3.00	0.278	.873	0.527	12.375	5.0	12.328	21.20	2.68	12.319	3.5	12.296	21.10	2.74
3.50	0.237	.745	0.449	11.870	7.5	11.768	20.20	3.64	11.789	7.5	11.688	20.00	3.78
3.64	0.225	.706	0.426	11.733	7.0	11.645	20.00	3.85					
3.65	0.224	.704	0.425						11.597	7.5	11.497	19.70	4.10
3.75	0.216	.679	0.409	11.677	7.5	11.577	19.80	3.96	11.509	8.0	11.397	19.60	4.28
4.00	0.195	.611	0.370	11.396	8.0	11.285	19.30	4.65	11.396	8.5	11.271	19.30	4.50
4.25	0.174	.546	0.330	11.140	13.0	10.855	18.60	5.20	11.172	10.0	11.002	18.90	4.95
4.50	0.153	.480	0.290	10.963	15.5	10.564	18.10	5.70	10.875	11.5	10.656	18.30	5.54
4.75	0.1325	.416	0.251	10.699	17.5	10.204	17.50	6.31	10.643	15.5	10.256	17.60	6.23
5.00	0.112	.352	0.222	10.546	20.5	9.878	16.90	6.85	10.490	18.5	9.948	17.05	6.76
5.25	0.091	.286	0.172	10.330	24.0	9.436	16.15	7.81	10.242	20.5	9.594	16.45	7.35
5.50	0.070	.220	0.133	10.113	28.5	8.887	15.20	8.57	10.017	22.0	9.288	15.90	7.90
5.60	0.062	.195	0.117						9.857	24.0	9.004	15.40	8.36
5.70	0.053	.166	0.101						9.760	24.0	8.916	15.30	8.54
5.75	0.049	.154	0.093	9.688	32.5	8.171	14.00	9.80					
5.80	0.045	.141	0.085						9.520	23.5	8.731	14.95	8.85
5.85	0.041	.129	0.077	9.456	35.0	7.746	13.30	10.50					
5.95	0.0325	.102	0.062	9.183	40.0	7.034	12.05	11.75					
6.05	0.024	.075	0.046	9.039	42.5	6.664	11.40	12.37					
6.15	0.016	.0502	0.030	9.039	42.5	6.664	11.40	12.37					
6.25	0.0075	.0235	0.014	8.998	47.5	6.079	10.40	13.40					

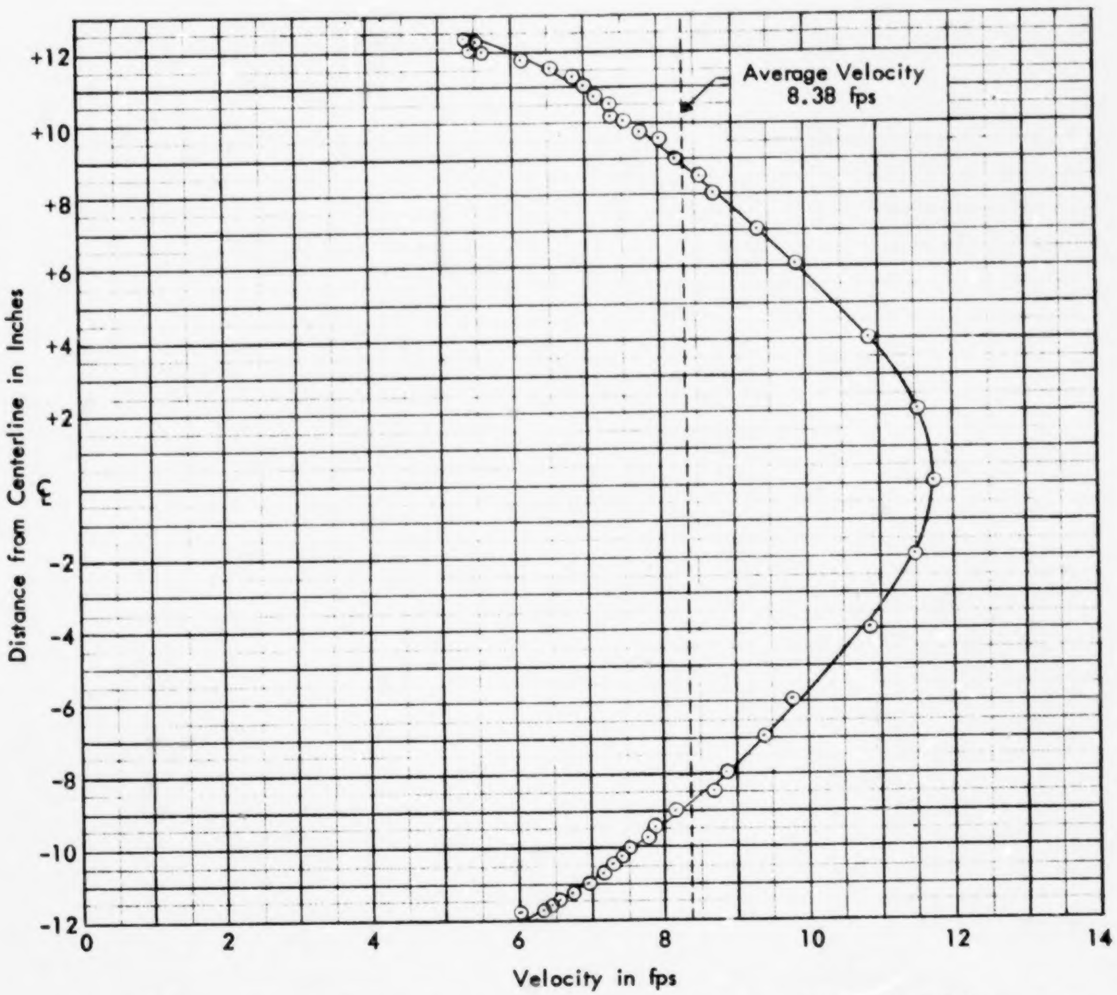


Fig. B-1 - Velocity Distribution in 24 In. Helical Lock Seam Pipe with 2-2/3 in. by 1/2 in. Corrugations

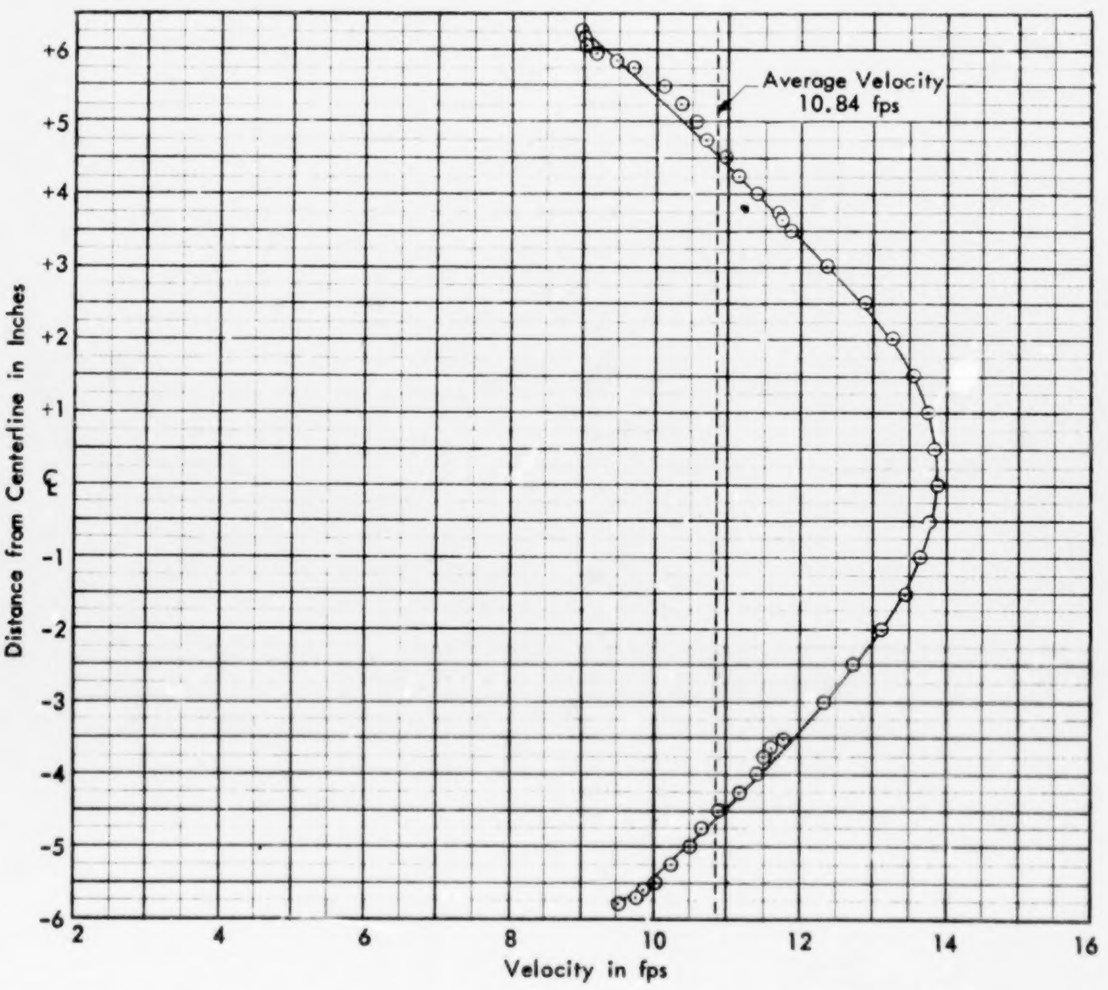
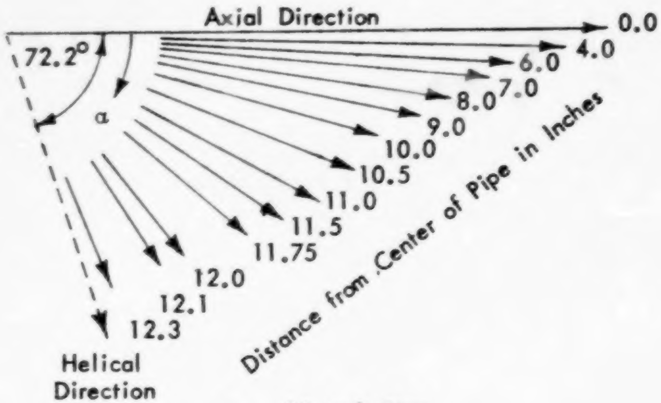
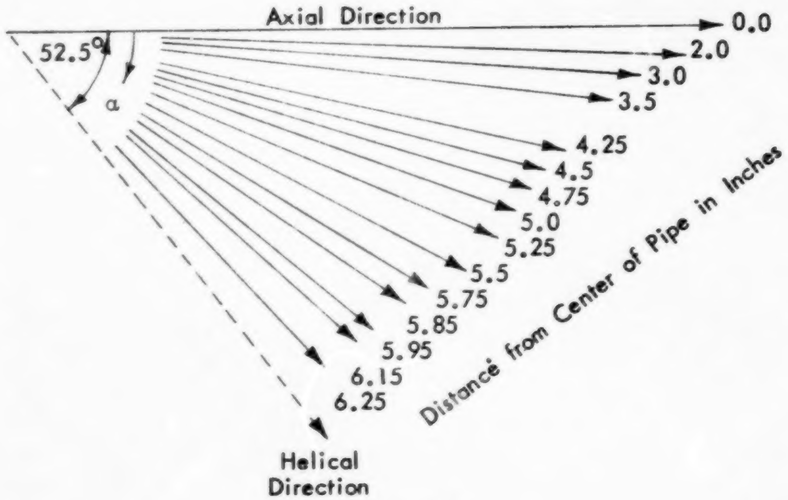


Fig. B-2 - Velocity Distribution in 12 In. Helical Lock Seam Pipe with 2-2/3 in. by 1/2 in. Corrugations


Axial Direction
0.0
4.0
6.0
7.0
8.0
9.0
10.0
10.5
11.0
11.5
11.75
12.0
12.1
12.3
72.2°
α
Helical Direction
Distance from Center of Pipe in Inches

24 Inch Pipe


Axial Direction
0.0
2.0
3.0
3.5
4.25
4.5
4.75
5.0
5.25
5.5
5.75
5.85
5.95
6.15
6.25
52.5°
α
Helical Direction
Distance from Center of Pipe in Inches

12 Inch Pipe

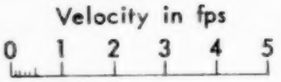
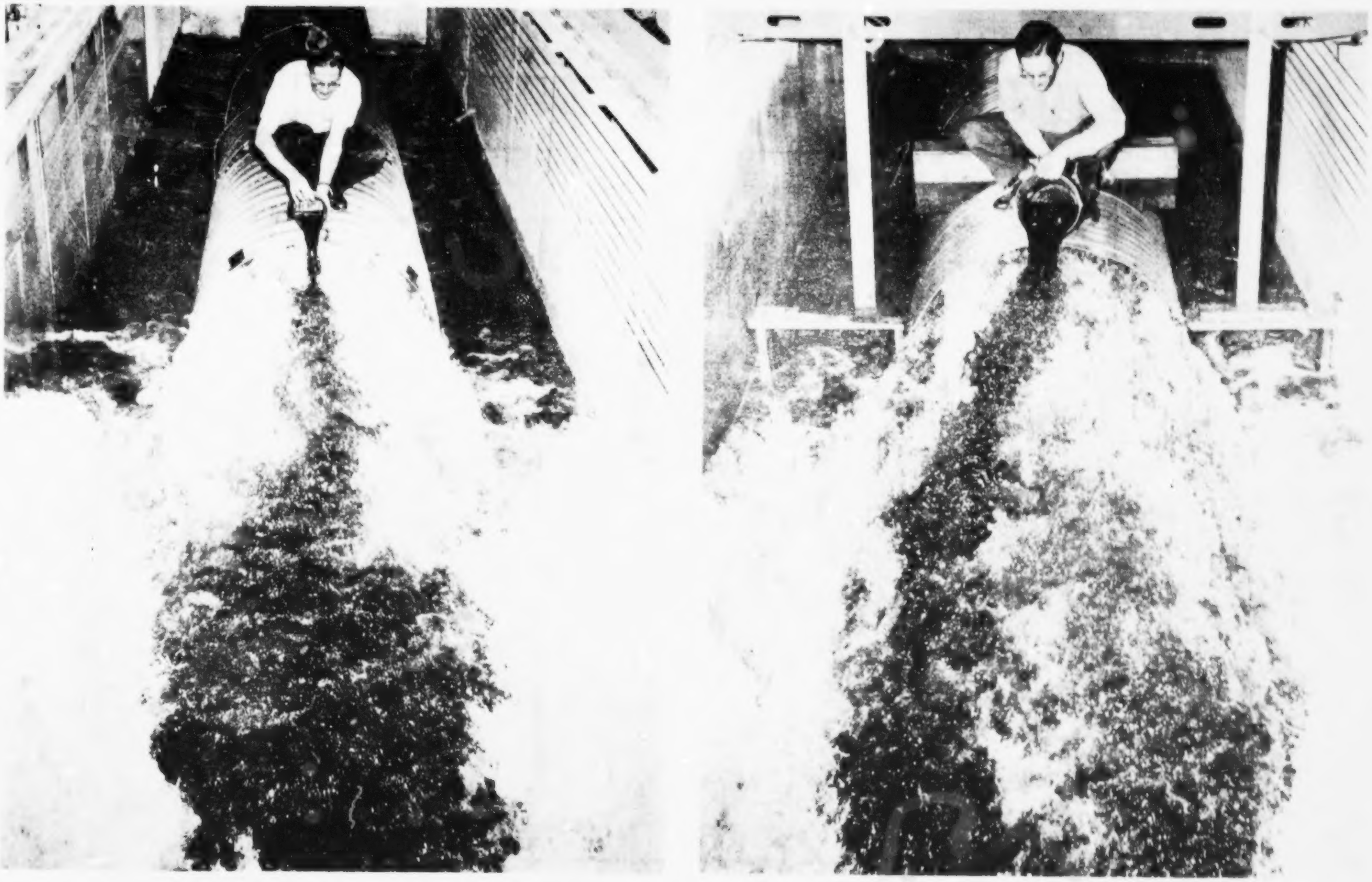

Velocity in fps
0
1
2
3
4
5

Fig. B-3 - Velocity Vectors, Top Halves of Pipes for 24 in. and 12 in. Helical Lock Seam Pipe with 2-2/3 in. by 1/2 in. Corrugations



a. Annular Pipe, 6 in. by 1 in. Corrugations

b. Helical Pipe, 2-2/3 in. by 1/2 in. Corrugations

Fig. B-4 - Flow Direction at 48 in. Pipe Outlets

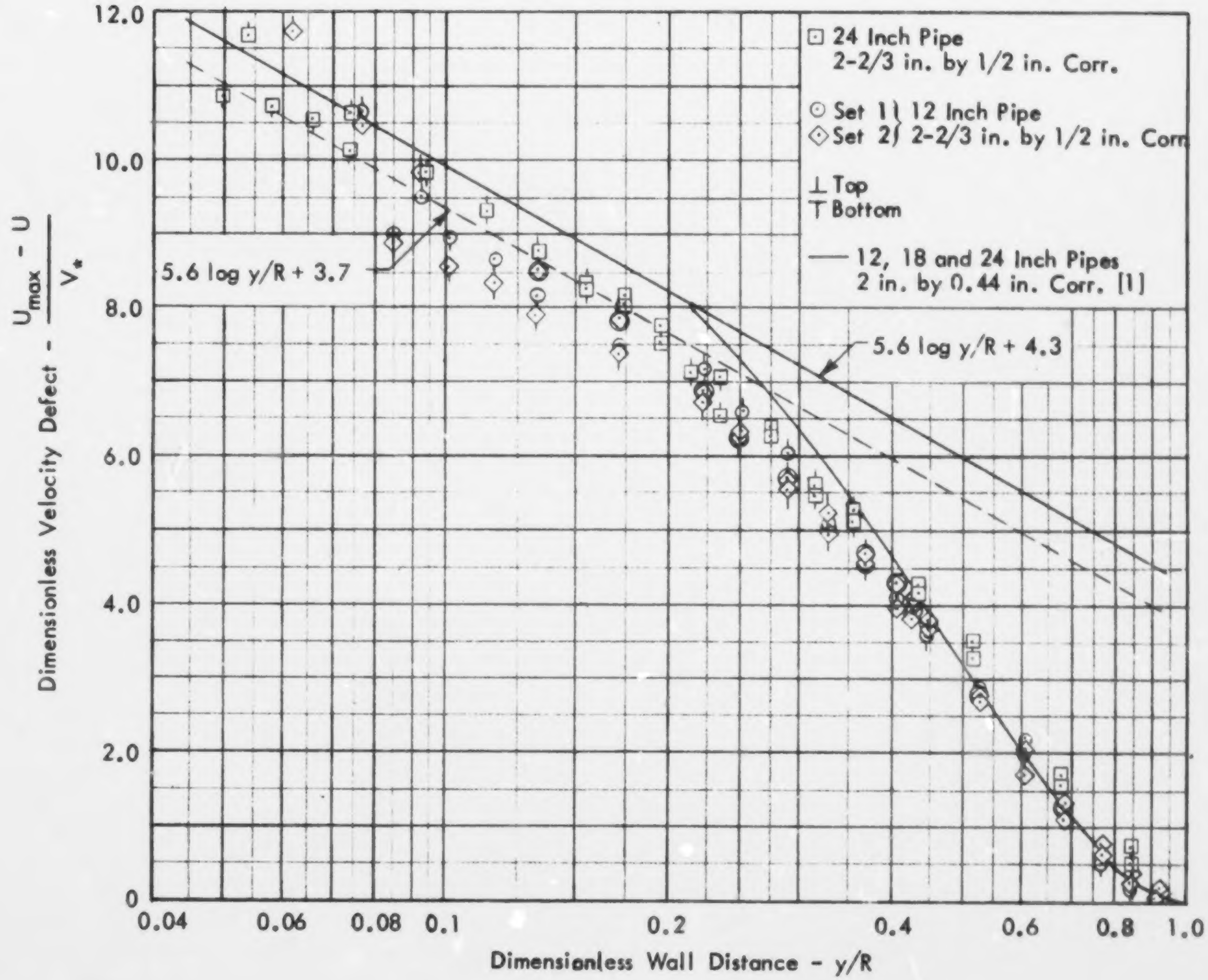


Fig. B-5 - Velocity Profiles in Defect-Law Form

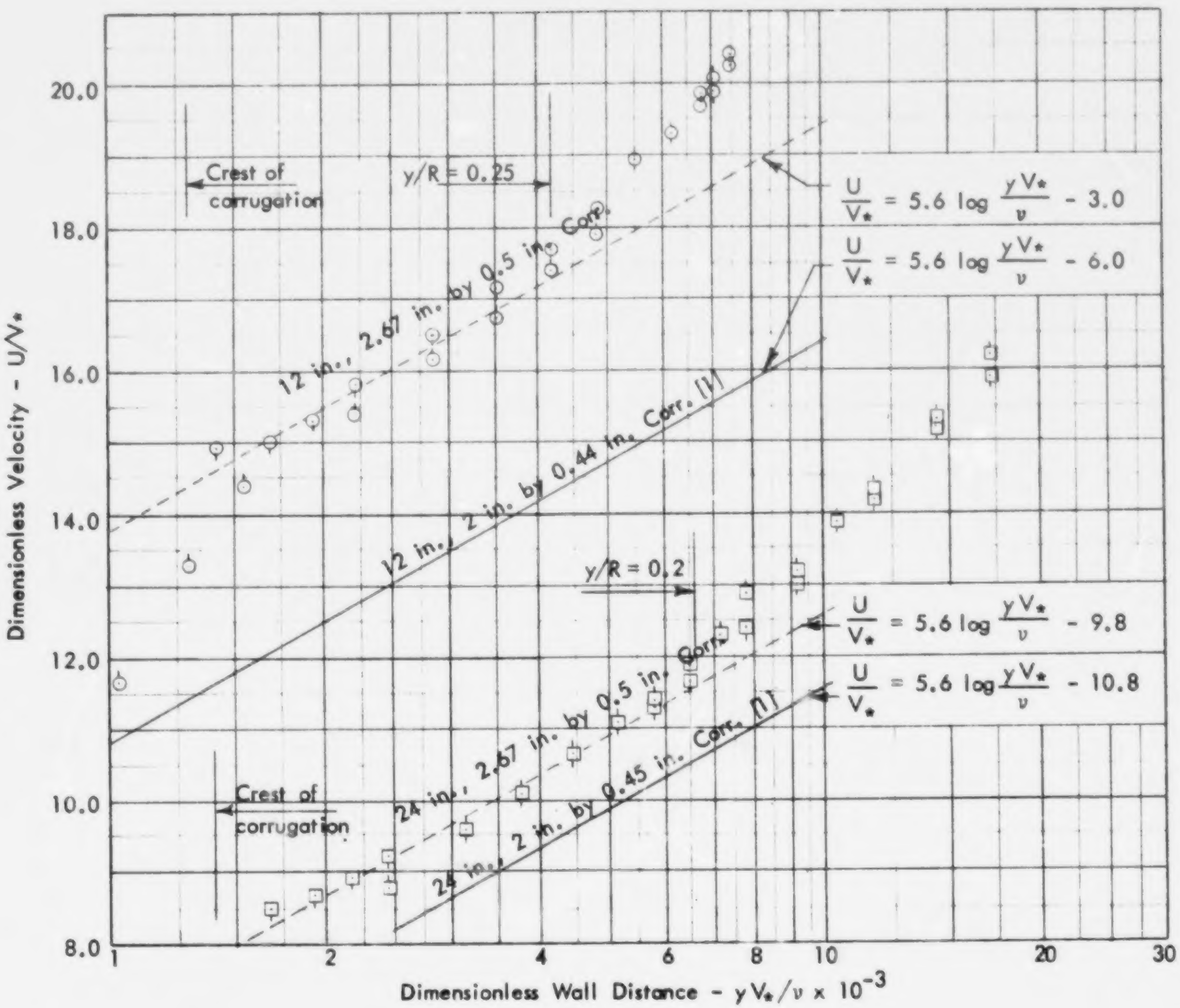


Fig. B-6 - Velocity Profiles in Law-of-the-Wall Form

APPENDIX B

CORROSION SECTION MEMO REPORT CSR 74-2
PERFORMANCE OF LaSALLE ILLINOIS ALUMINUM STORM DRAIN SYSTEM

FIRST YEAR INSPECTION

by

T. J. Summerson
Kaiser Aluminum & Chemical Corporation
April 24, 1974

BACKGROUND

In 1972, with Federal aid (EPA), the City of LaSalle, Illinois, replaced an old storm drain system with an aluminum (Alclad 3004 and 5052) storm sewer system.

Annual inspections were planned for the first 10 years service. Representatives of Kaiser Aluminum and Chamlin & Associates (engineering consultants for the City of LaSalle) are to inspect and to take samples for laboratory study on durability of the aluminum drain system.

SUMMARY

Aluminum storm drain system is in excellent condition after one year service. All of the Alclad 3004 samples show corrosion is confined to the thin cladding layer. While there have been some pinhole perforations found in the crown section of the 5052 alloy arched pipe, this structure is still sound.

Orange-red-brown (rust-like) discolorations were found on concrete catch basins as well as on the aluminum pipe. Analysis showed this to be amorphous iron oxides which convert to hematite (Fe_2O_3) with calcining.

Yellow-brown discolored deposits removed from the invert areas of the aluminum pipe were found to be predominantly calcium

carbonate, i.e., typical scale from the water. (The yellow-brown color was due to traces of iron oxide, i.e., rust).

STATUS

Annual inspections and laboratory analyses of samples removed will continue, as planned.

FIELD INSPECTION

The one year inspection was made on August 16, 1973. The inspection party consisted of

Chamlin & Associates:	Jim Giordano
	Al Witzeman
Kaiser Aluminum:	D. C. Thomas
	Len Hall
	T. J. Summerson

Inspection of the storm drain system interior was started at the outfall end of the 72 inch diameter Alclad 3004-1 x 6 pipe. Figure 1 shows the entire system and points of inspection.

Location #1

Only the 40 foot length of pipe under the railroad tracks shows any corrosion. The section of 72 inch aluminum drain underneath the CRI & P railroad tracks is encased in a steel tunnel liner. (The tunnel liner was installed to assist in support of heavy loads of railroad rolling stock.) There is a 3 - 4 inch dead air space between the steel outer liner and the aluminum. The outside surface of the aluminum pipe, facing the steel liner, was coated with a bitumastic.

Corrosion is a superficial, general etch type of attack which has given the metal a dark gray - black soot coloration which rubs off. Corrosion of this 40 foot section seems unusual because corrosion is confined to the upper half of the inside diameter. It also seems to be more apparent on the upstream side of the corrugation.

The first metal sample (3 x 4 inches) was taken from the crown area of the 72 inch diameter pipe, encased in the steel tunnel liner. The steel liner showed scattered small rust modules when seen through the hole where the aluminum sample had been removed. (The outside surface of the aluminum was coated with some type of bituminous paint.) The hole in the aluminum pipe was covered with a patch, using self tapping electrogalvanized steel fasteners.

Elsewhere along the pipe to the first man-hole at Canal Street, there is little evidence of corrosion. Occasionally, there is exudation of white corrosion products and dissolved salts from ground waters at the seams, but nothing of any consequence.

Location #2

At the first man-hole (Canal Street) we find evidence of yellow-red flocculate precipitate in residual water, standing in the corners of the concrete catch basin. It appears the water comes in through leaks in the concrete. The red colored flocculate is probably oxides of iron.

The pH of the water flowing through the pipe is 6.5 according to pH paper measurements made at the first man-hole.

The second metal sample (one inch dia.) was taken from the 66 inch diameter pipe, about 25 feet further back from the first man-hole towards the steep sloping pipe. The sample position is 2/3 up the side, towards the crown. The soil side of the sample shows etch-like attack and the inside surface is unaffected. The backfill is sand.

More yellow-brown scale deposits were collected from the surface of the aluminum pipe near the base of ths steep slope section. (Previous XRD analyses revealed this to be calcium carbonate.) The aluminum underneath shows no attack where scale existed.

Intensive inspection of the steep slope portion of the pipe was made in order to determine whether there had been any accordian effect (compaction of corrugations) caused by excessive loads on the pipe. A 15 foot ladder was used to facilitate the inspection. Figures 2 and 3 show the pipe interior. There appeared to be no structural problems or corrosion. The rust discolored calcium carbonate scale is obvious. A water sample was obtained.

Location #3

Entrance to the storm drain system was next made through a manhole at the top of the steep slope section (1st and Wright.) Upstream is the half round, arched metal pipe (5052) with a flat concrete floor. The width of the main drain is about 11 feet and height is about 5 feet.

The concrete floor has fine, longitudinal cracks in it with occasional white-gray colored product exudating from the cracks.

The 0.125 inch thick 5052 structural plate (Bedford lot 710719) shows scattered blistering and pin hole perforations at many points from 1st to 3rd street (See Figure 4). These occur randomly along the crown and side walls. Usually, there is a buildup of WCP (white corrosion product) around each pinhole with some bleeding of the white CP down the metal surface. Also, typically, larger areas (up to one inch in diameter) are found where the metal has lifted or blistered due to internal pressure from the formation of sub-surface corrosion products.

A 3-1/2 x 4-1/2 inch metal sample (3rd sample) was taken from the crown-side wall area. This sample contained a typical pinhole perforation--blistering corrosion (Intersection of 1st and Wright Streets). A sample of the selective backfill (sand) was also obtained. A patch was placed over the hole and held in place with metal self tapping fasteners. Close visual examination of the metal sample revealed mounds of sand firmly attached to those points where pinhole perforations were found. This is probably due to the cement-like affect of WCP and moist backfill). Elsewhere, the soil side was in good condition. In other words, about 99 percent of the 5052 surface is unaffected.

The occurrence of red-orange rust colored, gelatinous deposits was seen at bolt holes along the bottom of the half-round arched pipe. See Figure 5. (This is the same amorphous iron oxide material as previously mentioned.) The galvanized steel bolts and the aluminum appear to be relatively unaffected by the presence of these deposits.

At this point, inspection was delayed for 2 hours by a rain storm which increased markedly the water flow through the drain system.

Location #4

Bucklin between 8th and 9th. The 30 inch diameter pipe looked good. Metal and soil samples were taken.

Location #5

Bucklin and 10th Street. The 44-inch pipe flows into 18 inch and 15 or 12 inch diameter pipes. All look good. (Sample taken from the 18 inch diameter pipe and soil.)

Locations #6 & 7

9th and Marquette. Pipes examined at intersection. All four pipes in good appearance. Soil and metal sample #6 were taken from 36-inch diameter pipe, north of manhole. Soil and metal sample #7 were taken from the 18-inch diameter pipe, west of manhole.

Location #8

6th Street, between Wright and Bucklin. Red-orange flocculate deposits were noted exuding out of cracks and pores of a concrete catch basin, away from the aluminum pipes. Walking up the pipe towards Wright Street, same red-orange deposits noted exuding out of side wall laps of aluminum pipe. Picking away the orange top layer, reveals a shiny black underlayer. Behind this black layer is bright, unaffected aluminum. There is a slight odor of H_2S present.

Most of the red-orange deposits are observed in the lower portions of the drain, towards Bucklin, and in the catch basin. Ground waters (high water table) are prevalent, forcing water into the aluminum pipe and concrete catch basin. As you walk "up hill" towards Wright Street, the presence of red-orange exudation and scale disappears. The pipe is bright and clean.

The orange colored deposits had been submitted earlier by Cliff DeGraff from this area. X-ray diffraction analysis identified these as a hydrated iron oxide (hematite). The underlying black deposits are believed to be less highly oxidized iron oxide (magnetite), which will convert to the red-orange oxide when sufficient exposure to air (oxygen) allows complete oxidation to occur.

A soil, water and metal (Sample #8) were taken from the 60-inch pipe, west of the manhole on Wright.

Location #9

7th Place and Marquette. Some nodules of corrosion products were noted in the invert area of the 48-inch diameter pipe. Soil, water and metal samples (#9) were taken.

LABORATORY EVALUATION

Soil and metal samples were tested by Kaiser Aluminum at the Center for Technology (CFT), in Pleasanton, California. The water samples were sent out for analysis by Chamlin & Associates.

At CFT, pH and minimum resistivity of the soil samples were measured in accordance with the State of California, Department of Highway method 643 B. The results are shown below.

Sample # & Type	pH	Minimum Resistivity, ohm-cm
3 - sand	8.3	2,200
4 - brown sand	8.5	3,900
5 - dark brown sand	8.4	8,200
6 - sand	8.7	2,600
7 - brown sand	8.1	1,000
8 - sand	7.9	2,700
9 - gravel	8.7	2,900

The metal samples were photographed on soil and inside surfaces, before and after removing dirt and any corrosion products. The dirt was washed off and corrosion products removed by ASTM method 67-1 (hot chromic-phosphoric acid cleaner).

Sections were cut out of the metal samples which contain the deepest appearing corrosion on both the soil and the inside surfaces. These sections were mounted in epoxy and polished, prior to microscopic examination. The maximum depth of corrosion and the predominant forms of corrosion were photographed.

A typical metal sample for Alclad 3004 pipe is shown in Figure 6, after the dirt and corrosion products have been removed.

The metallographic cross-sections for all Alclad 3004 samples are shown in Figure 7. In all instances, corrosion is confined to the thin cladding. On the soil side of sample 7, all of the cladding appears to have been consumed. Examination of Figure 6 shows, however, that better than 60 percent of the cladding is still apparent on the soil side of this sample.*

The appearance of the pit-blisters, perforated 5052 alloy arched pipe is shown in Figure 8 (before cleaning) and Figure 9 (after cleaning). When the sample was first taken, damp sand and corrosion product formed mounds over the three corroded areas on the soil side. (The black circles indicate the extent of these mounds.) On drying, the sand and most of the WCP sloughed off. When cleaned, the blister-up lift appearance of corrosion becomes obvious. (Figure 9).

A cross-section through one of the pinhole perforations is shown in Figure 10. The uplifting reflects the directionality of the grain structure and the corrosion.

The three water samples (locations 2, 8 & 9) were analyzed for Chamlin and Associates by Limnetics, Inc. Their results are reproduced below.

Analysis: Result: mg/l except as noted

Parameters	Sample #1	Sample #2	Sample #3
Alkalinity	285	204	305
Copper	<0.02	<0.02	<0.02
Nickel	0.07	0.06	0.06
Iron	<0.05	0.06	0.45
Min. Resistivity	6.2×10^{-4} µ ohms-cm	5.7×10^{-4} µ ohms-cm	5.6×10^{-6} µ ohms-cm

---

*Note all cross-sections are taken from an area exhibiting the greatest amount of corrosion. Usually, such areas represent the extreme and are not indicative of the majority of the exposed surfaces.

The scale and rust colored gelatinous deposits taken from the aluminum pipes and from concrete catch basins were examined by X-ray diffraction (XRD), emission spectrography and by energy dispersive spectrographic analysis. As indicated earlier, the scale consisted mainly of $CaCO_3$ (calcium carbonate). Also found was $Ca(OH)_2$ and silicon in the form of silica. None of these compounds is corrosive towards aluminum.

Emission spectrographic analyses of the rust colored gelatinous deposits showed major elements present to be iron, calcium and silicon. XRD showed the calcium present as calcium carbonate and the silicon as silica (quartz). On calcining at 300°C, a crystalline iron compound, Fe_2O_3, was detected. (Until calcining, the iron was probably in an amorphous, hydrated iron oxide form.)

The calcium carbonate probably originates from dissolved salts in ground waters. The iron oxide is probably the product of anaerobic decomposition of iron compounds in the soils.

DISCUSSION

The good performance of the Alclad 3004 pipe is typical and follows the experiences of literally thousands of other Alclad 3004 pipe samples examined under similar conditions of service for periods as long as 15 years.

The pit-blisters and pinhole perforations noted occasionally in the crown area of the 5052 alloy arched pipe is unusual in its occurrence. At this inspection, its presence is of nuisance value because there has been no loss in strength or structural integrity. While it is unlikely, further inspections will determine if pin hole perforations will increase in sufficient frequency to become a factor of concern. Moreover, it should be remembered that large sections and areas of the 5052 structural plate arch did not exhibit any evidence of corrosion.

The presence of the red-rust colored deposits on the aluminum pipe, while unsightly, has been no concern. It has been noted in the concrete catch basins and it appears to be oxide of iron.

ACKNOWLEDGEMENTS

Most of the colored photographs used in the first year's report were taken by Len Hall during the inspection. Handling the yeomen duty during the inspection were Al Witzman and Len Hall.

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best available copy.

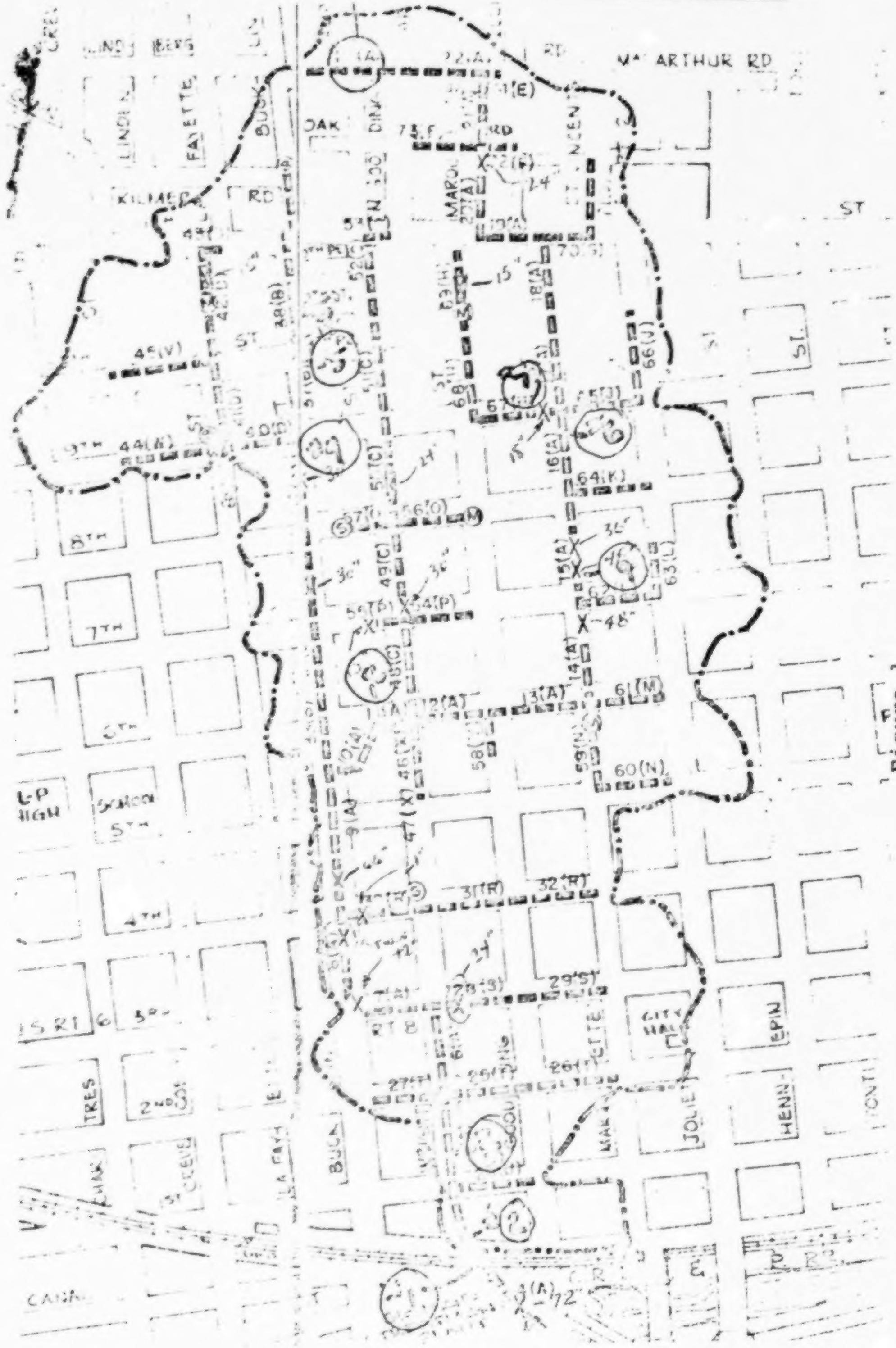

MacARTHUR RD
KILMER RD
OAK
FAYETTE
9TH
8TH
7TH
6TH
5TH
4TH
3RD
2ND
L-P HIGH SCHOOL
CITY HALL
JOLIET
HENN-EPIN
CANAL
RT 8
ST
45(V)
44(K)
64(K)
60(N)
3(R)
32(R)
29(S)
27(T)
26(T)
30"
36"
48"
66"
72"
24"

Figure 1

ALUMINUM STORM SEWER SYSTEM - LaSALLE ILLINOIS

Location of One Year Inspection Sites and Samples

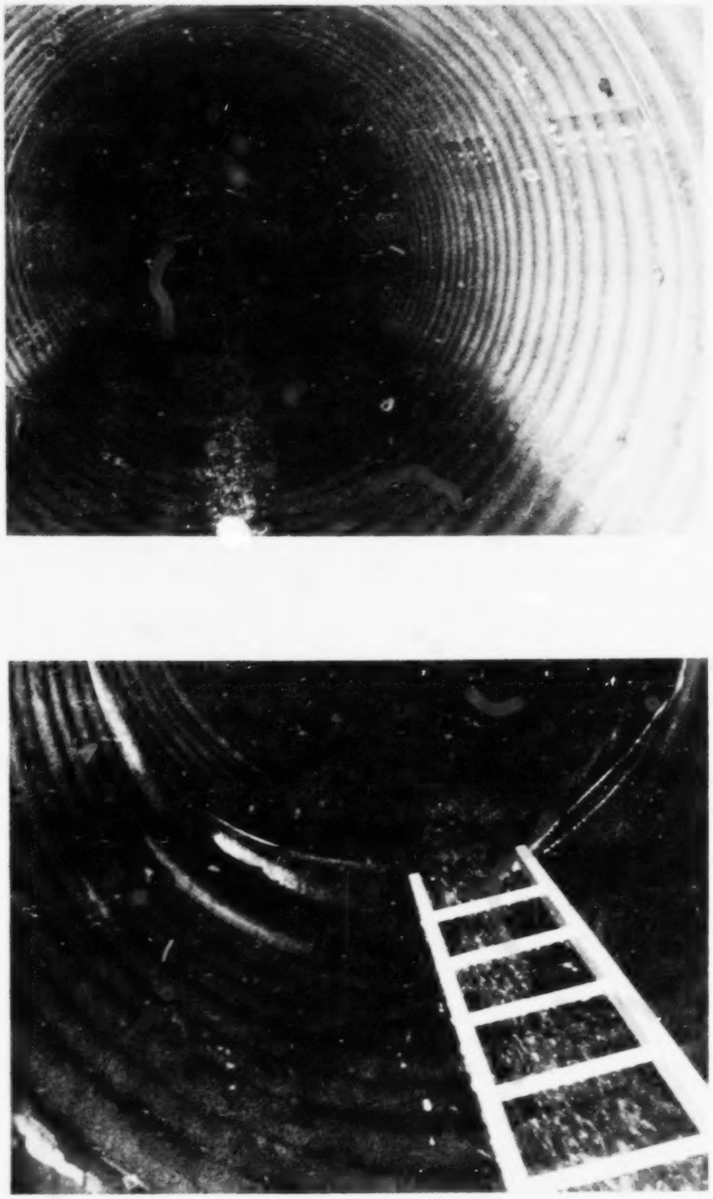


Figure 2

72-inch diameter Alclad 3004 pipe, looking up towards 1st & Wright Streets from Canal--One year inspection (8/16/73)

Brownish discoloration is the calcium carbonate scale formed with the passage of storm waters.

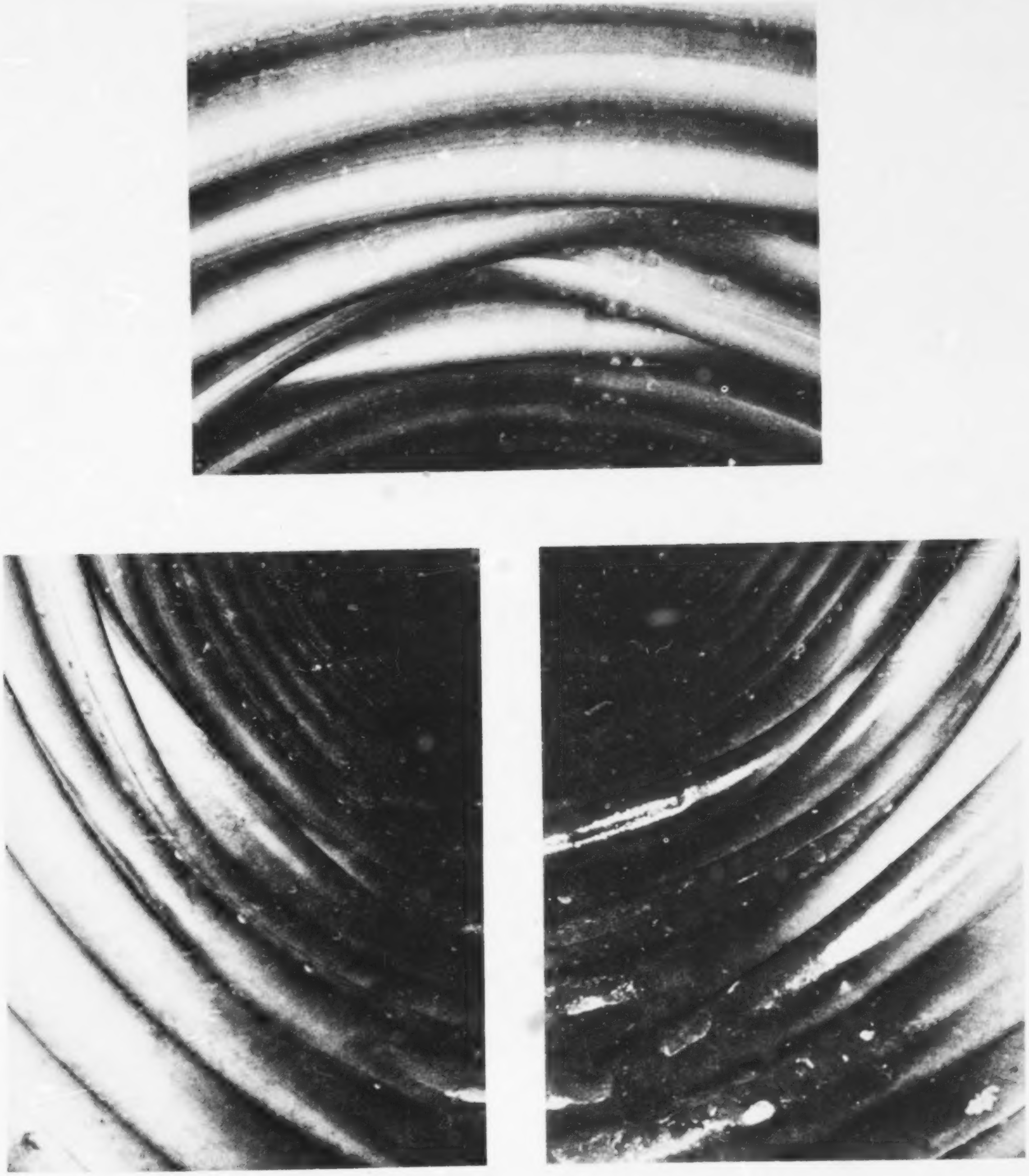
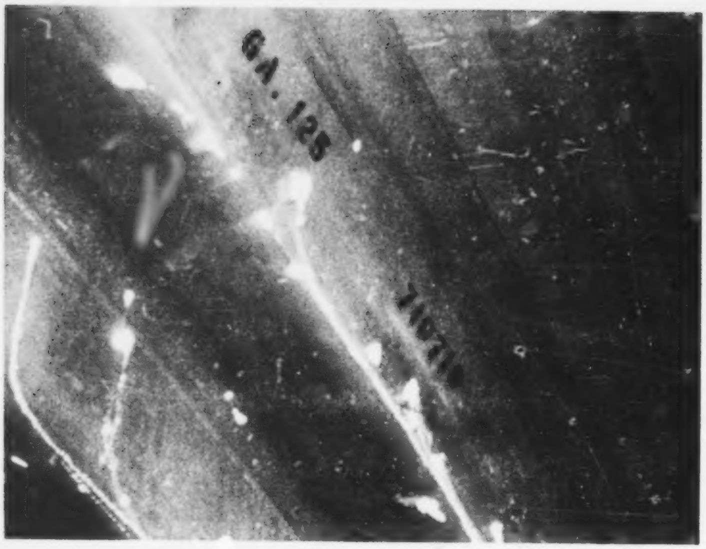


Figure 3

72-inch diameter Alclad 3004 pipe at the bend in steep sloped section below 1st and Wright - One Year Inspection (8/16/73).

Top shows roof section of pipe. Bottom photos show rust discolored calcium carbonate scale in invert area of pipe (Deformations or buckles made in pipe at time of installation).



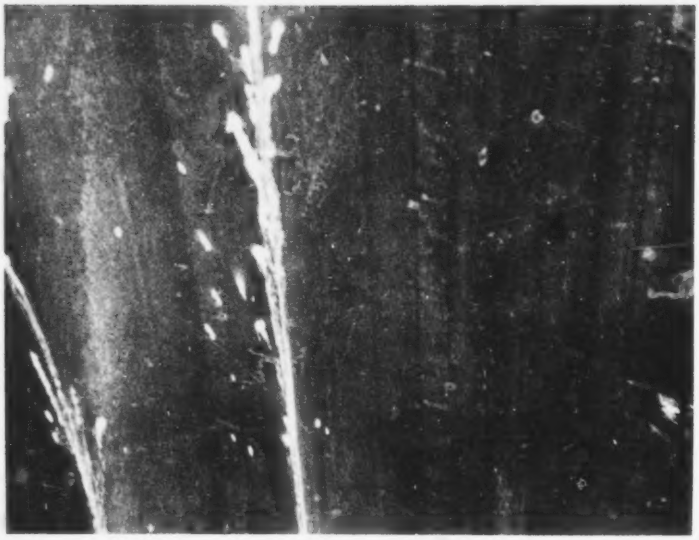


Figure 4

Pinhole perforations in 0.125-inch 5052 arched pipe--One year inspection (1st to 3rd Streets on Wright.)

Observed randomly in the crown and upper side walls. The buildup of white corrosion products (WCP) forms a nodule. Some bleeding of the WCP has occurred down the side from the nodules.

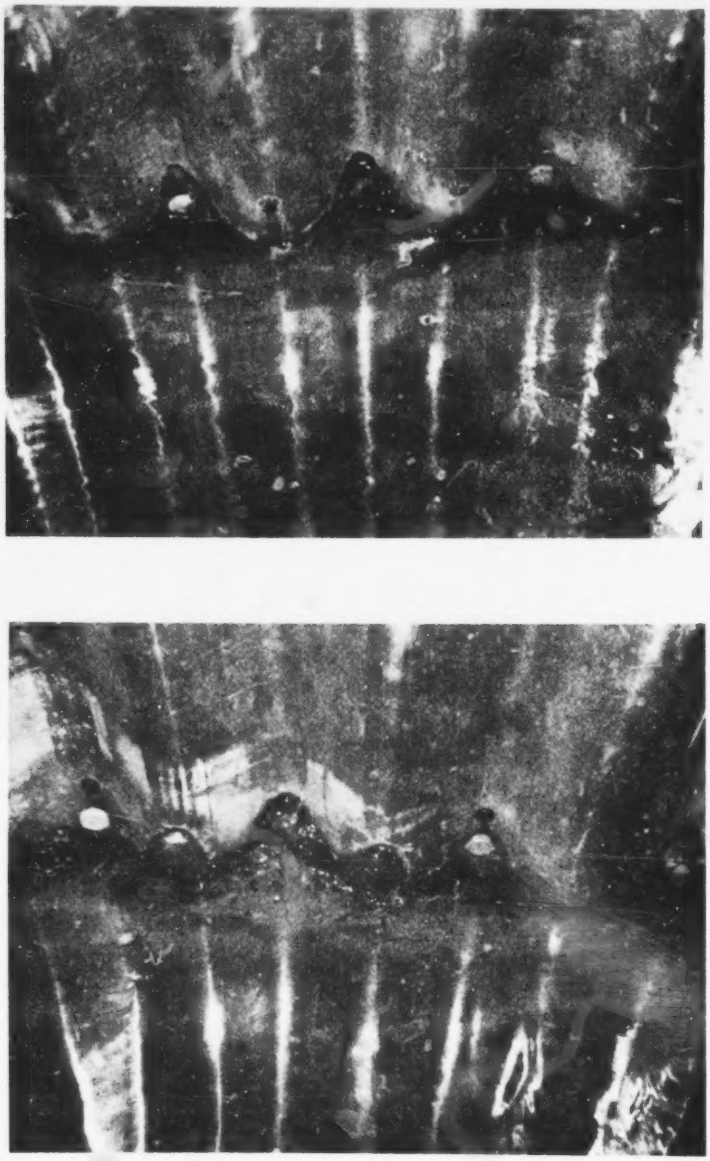


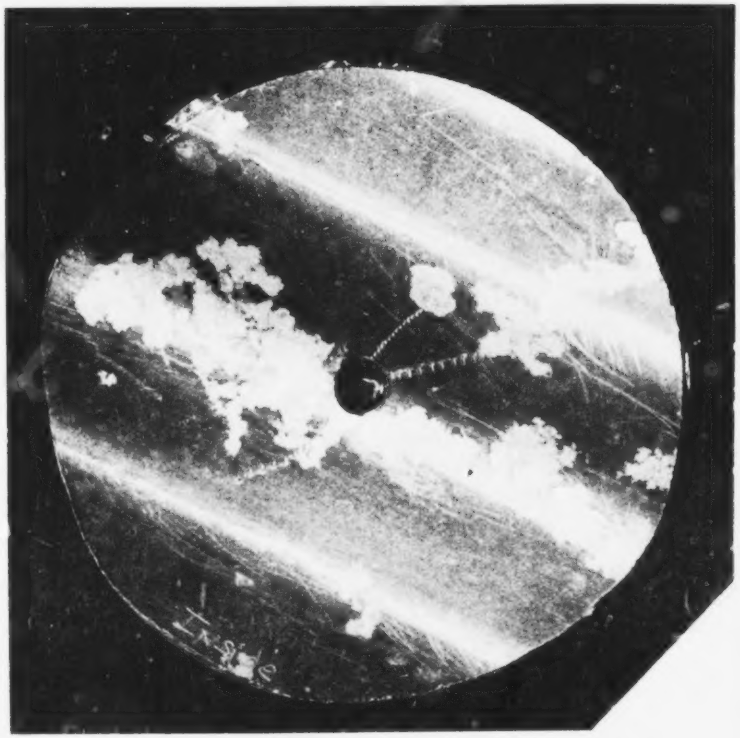
Figure 5

LaSALLE ILLINOIS - ONE YEAR INSPECTION

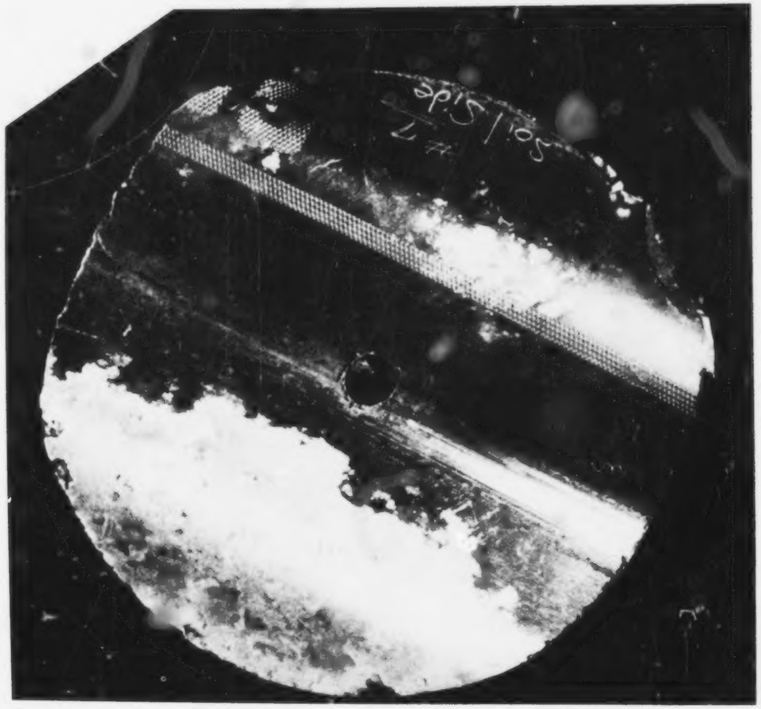
Gelatinous red-orange (rust colored) deposits exuding from bolt holes at the base of the aluminum, adjacent to the concrete floor. (1st & Wright). These have been identified as iron oxide.

The same deposits were noted in concrete catch basins elsewhere.

When deposits are removed, underlying aluminum shows no evidence of corrosion.



Inside Surface (73-2025)

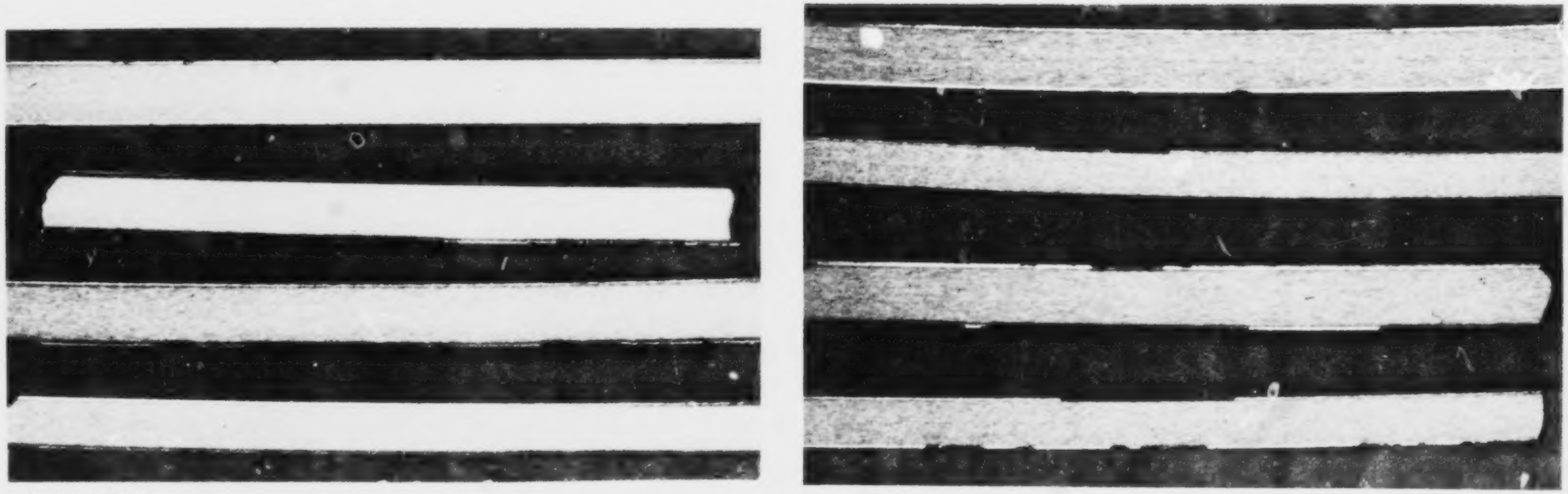


Soil Side (73-2024)

Figure 6

ONE YEAR INSPECTION - LaSALLE ILLINOIS
Aluminum Storm Sewer - (8/16/73)

Superficial, scattered attack of surface appears as the light colored areas in these photos. Sample 7 is from the 18 inch pipe at 9th and Marquette.



(M52492)

(M52493)

5X, HF-H_2SO_4 etch for 45 seconds

Figure 7

LaSALLE ILLINOIS ALCLAD 3004 STORM DRAINS

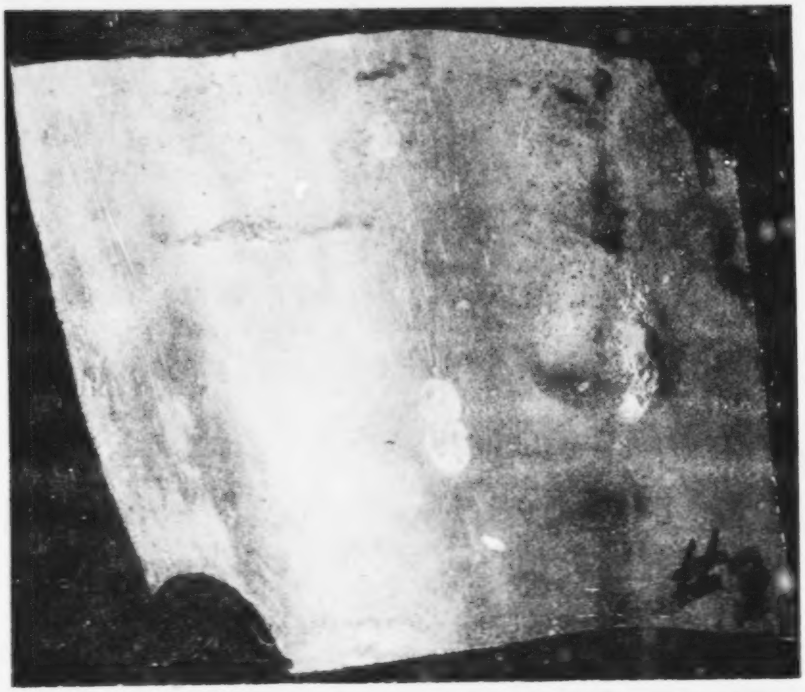
ONE YEAR SAMPLING, 1973

(Soil side down and inside surface up in these photos)

Left Photo, Top to Bottom:
Sample 1 - Tunnel liner, with scattered pits on inside surface (top) only.
2 - 66 inch diameter (below Wright Street).
4 - 30 inch diameter on Bucklin between 8th and 9th Streets.
5 - 18 inch diameter on 10th & Bucklin. Etch attack on the soil side (bottom) only. Confine to clad layer on samples 2, 4 & 5.

Right Photo, Top to Bottom:
Sample 6 - 36 inch diameter 9th & Marquette.
7 - 18 inch diameter 9th & Marquette.
8 - 60 inch diameter - 6th off Bucklin.
9 - 30 inch diameter - 7th & Marquette.

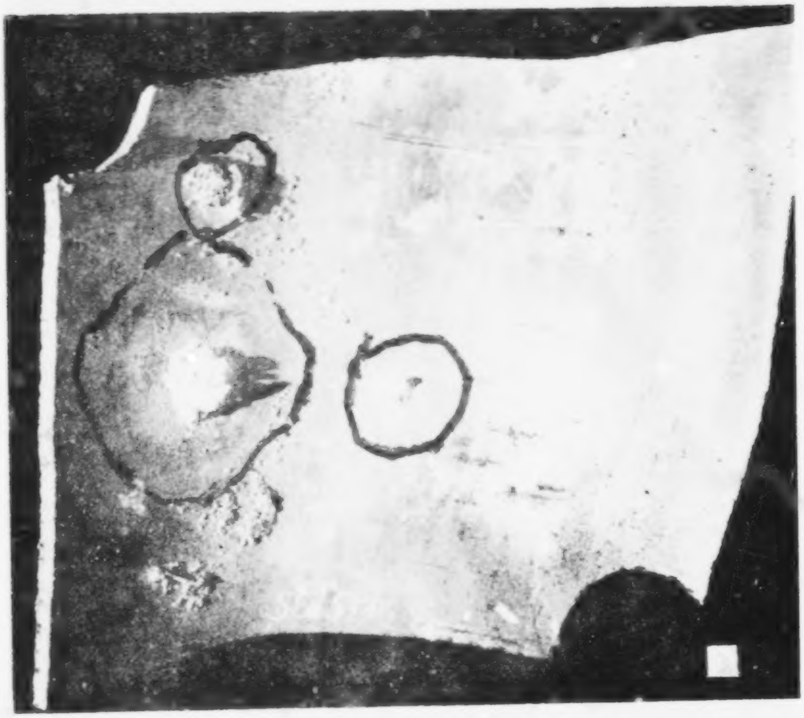
Corrosion confined to cladding layer on all samples. More attack noted on soil side (down) than inside. On sample 7, all of the cladding on this sample appears to have been consumed.



(73-1311)
Inside

Pinhole-blister perforations noted in crown area after one year. Top photo shows blister area with a slight amount of white corrosion products.

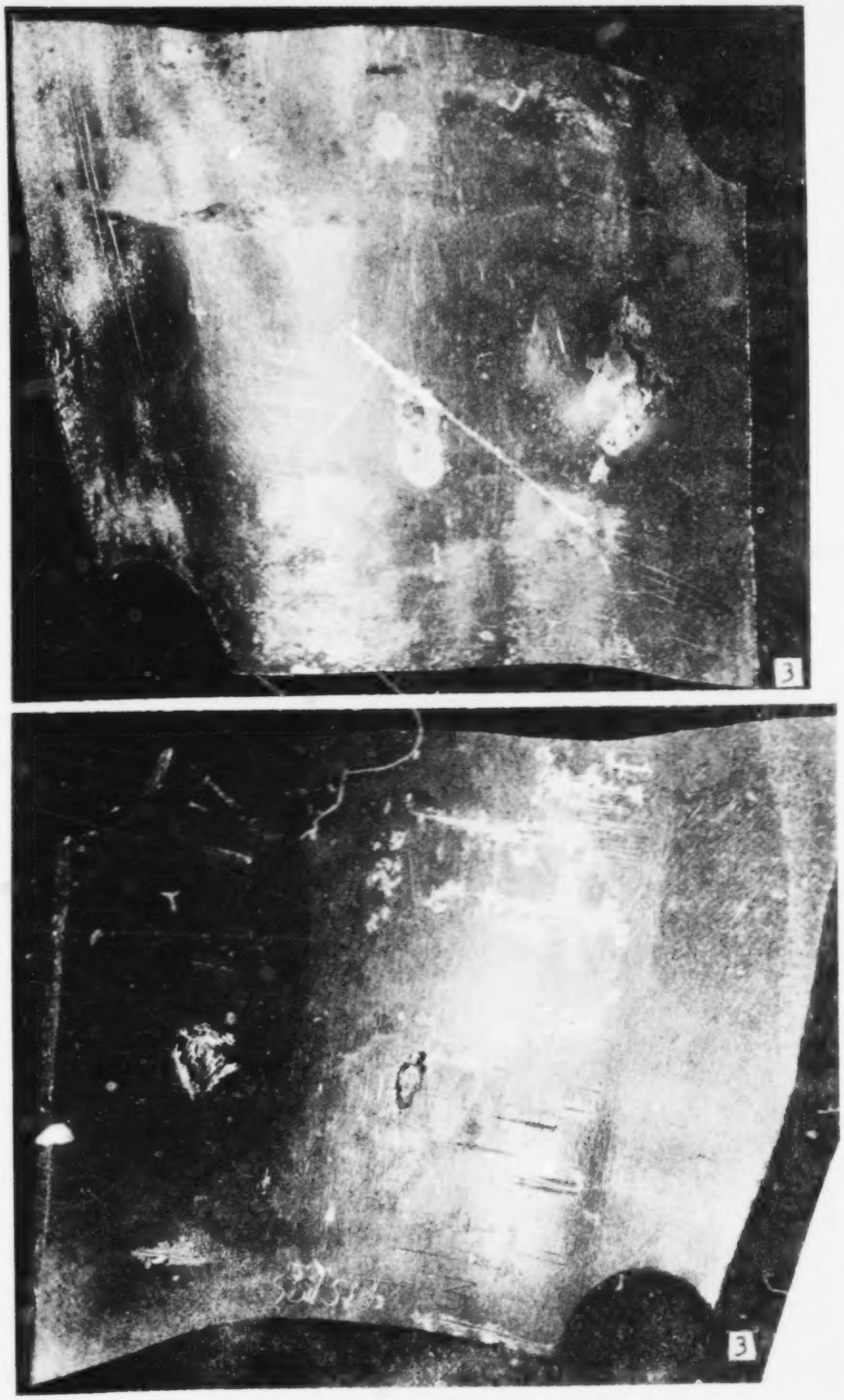
Lower photo shows the soil side with three distinct mounds of WCP. The black circles indicate area originally encompassed by sand backfill and gelatinous corrosion, deposits, prior to drying out.



(73-1310)
Soil Side

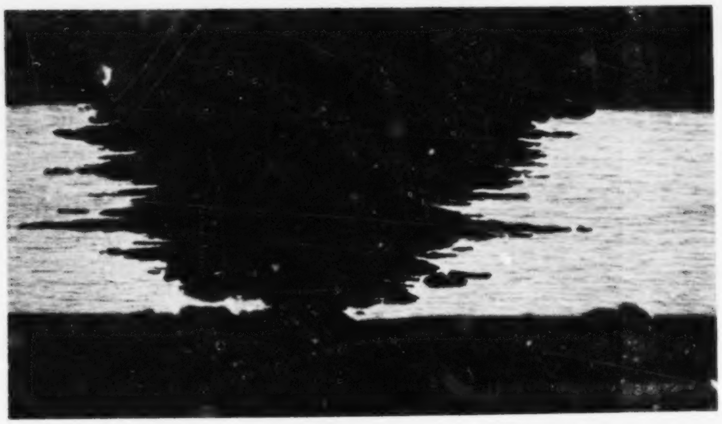
Figure 8

LaSALLE ILLINOIS STORM DRAIN-ARCHED 5052 PIPE

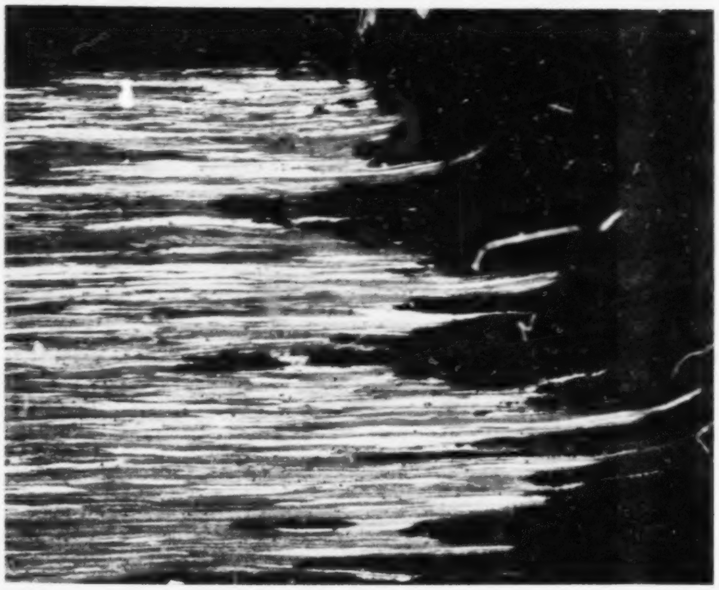


Pit-blister and pinhole perforations observed. Attack initiated from soil side where selective backfill (sand) was found. Much of the pitting occurs along lines and scratches formed during corrugating process.

Figure 9
LaSALLE ILLINOIS STORM DRAIN - 1 YEAR SAMPLE #3
5052 ALLOY ARCHED PIPE


Soil Side
Inside

10X, anodized-sensitive tint (M52491)



40X, anodized-sensitive tine (M52489)

Figure 10

5052 ARCHED PLATE - LaSALLE ILLINOIS

One Year Sample (Sample #3 - 1973)

Pit blistering occurs from soil side in a highly elongated grain structure.

APPENDIX C

MEMO REPORT

CSR 75-1

PERFORMANCE OF LaSALLE ILLINOIS ALUMINUM STORM DRAIN SYSTEM AFTER TWO YEARS' SERVICE

May 7, 1975

By

R. J. HOGAN

Kaiser Aluminum & Chemical Corporation

BACKGROUND

An aluminum storm drain system was installed by the City of LaSalle, Illinois, with Federal Aid (EPA), in 1972. The system includes Alclad 3004 culvert and 5052 structural plate.

Annual inspections are planned for the first 10 years' service. Representatives of Kaiser Aluminum, the City of LaSalle, Illinois State Highway Department, and Chamlin & Associates (consultants for the City of LaSalle) are to inspect the aluminum storm drain system for durability and performance.

The first annual inspection Ref. 1 (1973) revealed aluminum pipe was in structurally sound condition.

a. Corrosion was confined to the thin cladding layer on all Alclad aluminum samples.

b. Some pinhole perforations were found in the crown sections of a few sections of 5052 alloy arched pipe.

c. Orange-reddish brown discolorations on aluminum pipe and concrete were found to be amorphous iron oxides.

d. Deformation or buckling of a sharply inclined 72-inch diameter culvert below 1st and Wright Streets was noted.

SUMMARY

The aluminum storm drain system remains in excellent condition after two years' service with no evidence of structural damage.

In Alclad 3004 pipe samples, eight of the nine samples showed corrosion, if any, is limited to the thin cladding layer. The ninth Alclad 3004 sample has perforations which appear to be the result of dissimilar metal corrosion. This sample was taken adjacent to the end of a bare steel tunnel liner over the culvert. (The tunnel liner was installed under railroad tracks due to existing AREA specifications. Pipe to soil potentials indicated the steel liner must not have been isolated from the aluminum at the time of installation. Cathodic protection should be used to protect the steel and the adjacent aluminum.

With 5052 alloy structural plate, the pit-blister and pinhole perforation activity appears to have subsided.

There has been no further "accordioning", i.e. mechanical deformation of the steeply inclined 72 inch Alclad 3004 corrugated pipe located below 1st and Wright Streets.

STATUS

Annual inspections and laboratory analysis of samples removed will continue.

FIELD INSPECTION

The second annual inspection party, made on September 19, 1974, consisted of:

Chamlin & Associates	Jim Giordano Al Witzeman
Illinois State Highway Department	Jon Bourne
City of LaSalle, Illinois	Bill Mallie
Kaiser Aluminum & Chemical Corporation	Len Hall Cliff DeGraff Bob Vaterlaus Dave Thomas Dick Hogan

The storm drain inspection was started at the outfall end of the 72" dia. Alclad 3004 - 1 x 6 pipe, below Canal Street and the railroad tracks. Figure 1 shows the entire aluminum storm drain system and points out location of the 1973 and 1974 metal samples.

A 40-foot length of pipe under the CRI&P Railroad, encased in a steel liner, is coated with a dark oxide film (very light aluminum oxide), which most likely is due to condensate collecting on the inside of the pipe. This darkening was noted during the 1973 inspection. Sections on each end of this 40-foot length show relatively heavy corrosion (See discussion p.4 on Location 11).

Eleven aluminum samples, eleven soil and three water samples were removed during the inspection. The metal samples were removed with a two-inch hole saw. An aluminum cover patch, with a mastic sealer, was placed over the hole and attached with stainless steel metal screws. See Fig. 2. In addition, pipe to soil and pipe to water potentials were measured, using a Cu-$CuSO_4$ reference electrode. (Miller Potential Meter RE-5). Inspection notes of the eleven sites follow:

Location 1 - 20 feet south of manhole on Canal Street - Alclad 3004, 72" dia. - 1 x 6. No pitting or staining of culvert on water side. A 2-inch metal sample was removed with a hole saw. Pitting of the cladding on the soil side is evident. The soil is a granular backfill (brown sand).

The steep angled (sloping) 72" dia. - 1 x 6 pipe, one block north of Canal Street, shows no further evidence of movement or deformation, i.e. "accordioning". Initial movement and deformation of the 45° angled pipe is believed due to earth compaction or settling during the first year of service.

Location 2 - 175 feet north of manhole on 1st and Wright Streets, Alloy 5052 arch. pipe. (This location corresponds with sample #3 of the 1973 inspection). Red-orange rust-colored deposits (amorphous iron oxide) noted during the 1973 inspection are now less evident and also drier. The frequency of the scattered pit-blistering and perforations of the 0.125-inch thick 5052 structural plate, does not appear to have increased during the year. In fact, the exudation of gelatinous corrosion product, noted in 1973, is almost dry and appears inactive. A 1.5 x 3-foot area of the structural plate (Figure 3) containing 60 corrosion sites (200 feet north of the manhole) was marked off to be inspected again next year, in 1975. A second 1.5 x 3 foot area was identified and etch cleaned, using NaOH, to remove staining caused by corrosion product run-down. This area will also be inspected in 1975 for evidence of further activity (Figure 4).

Location 3 - 40 feet east of manhole, 3rd and Bucklin. Alloy 5052 arch pipe. There was no evidence of pit-blisters or perforations in this area. A sample was removed at random. Superficial corrosion is evident on the soil side; no pit-blistering, however.

Location 4 - 24 feet east of manhole on 6th Street between Bucklin and Wright. Alclad 3004, 60" dia. - 1 x 6.

Heavy deposits of hydrated iron oxide (hematite) as identified by x-ray diffraction, are still present in this area; both on the concrete catch basin and the water side (inside) of the pipe. The high water table in this area probably creates pressure for heavy flow of fluid in the backfill to exude into the pipe and concrete. This was also noted while removing a 2-inch diameter metal sample (Figure 5).

Location 5 - 3 feet south of manhole on 6th between Bucklin and Wright - Alclad 3004, 60" dia. - 1 x 6.

Similar deposits of hematite are present on the pipe in this location. Etching of the cladding layer on both the soil and water side of the pipe is present. A high water table is also present at this location.

Location 6 - Manhole, S.W. corner, 7th and Gooding - Alclad 3004 Corlix vertical catch basin.

The fill behind the metal sample at this location was dry. Neither side (soil or water) of the pipe experienced etching or staining.

Location 7 - 83 feet north of manhole, 4th and Bucklin - Alclad 3004, 66" dia. - 1 x 6. A slight staining of the cladding was noted on the sample removed from this area.

Location 8 - 65 feet south of manhole, 4th and Bucklin - Alclad 3003, 42" dia. - 1 x 6. The water side of the pipe shows minor staining. Soil side of the sample removed shows some etching of the cladding.

Location 9 - 45 feet south of manhole, 7th Place and Marquette - Alclad 3004, 48" dia. - 1 x 6. Inside of the pipe is clean, no deposits or staining. The soil side of the sample indicates some pitting of the thin cladding layer.

Location 10- 1 foot west of manhole on Linburg Road and Marquette - Alclad 3004 15" dia. Corlix.

The water and soil sides of this pipe are clean and show no corrosion.

Location 11- 185 feet south of manhole on Canal Street - Alclad 3004, 72" dia. - 1 x 6. During the morning inspection of this section of pipe, we noticed several areas of white corrosion product on the inside of the pipe at two locations. These locations correspond to the ends of a bare steel tunnel liner which encases the culvert in an area where the CRI&P rail spur runs overhead. A metal sample was taken. We found several perforations in these two areas which extended approximately 15 feet out from the ends of the tunnel liner. The pipe to soil potential in this area was -0.50 volts as compared to -0.72 volts in other areas not showing perforations. See Table 1 and Figure 6.

LABORATORY EVALUATION

Eleven soil and metal samples plus one water sample were tested by Kaiser Aluminum at the Center for Technology in Pleasanton, (Ref. 2). (Two water samples were given to Chamlin & Associates for testing locally.)

A. Soils.

Resistivity and pH of the soil samples (Table 1) were measured in accordance with the State of California, Department of Highways Method 643B. Soil resistivities and pH data were comparable with the 1973 results.

B. Water.

Analysis of the one water sample sent to CFT is given below: (Sample removed near the outfall end of the system.)

Element	Quantity (mg/l)
Chloride	170.
Sulfates	600.
Nitrate(NO_3)	17.6
Total phosphate (ortho 0.20)	0.33
Total solids @ 105°	1,368.
Ca	185.
Mg	71.
Na	96.

pH - 7.8

Conductivity - 1,670 μ mho (600 Ω cm)

(No heavy metals detectable)

C. Metal Samples.

The aluminum samples were photographed on both the soil and inside surfaces before and after cleaning. The dirt was washed off and the corrosion products were removed by ASTM method 67-1 (hot chromic-phosphoric acid cleaner). Figures 7 and 8 show Samples 4 and 7 before and after cleaning of soil and water sides. Representative sections were removed from the eleven metal samples, mounted in epoxy and polished prior to metallographic examination. Cross sections of the nine Alclad 3004 samples are shown in Figure 9 at 5X. Corrosion, if any, is confined to the protective cladding layer, except where galvanic corrosion with steel caused perforation at one location (location 11).

Pit-blisters and pin-hole perforations (Figure 10) found on the 5052 arch pipe after one year (1973) do not appear to have increased in size or frequency and they are not detrimental to the structural integrity of the pipe.

Cross sections of the 5052 arch pipe samples are shown in Figure 11. The bottom sample shows the normal type of pitting corrosion in 5052 alloy. The top sample contains the lamellar pit-blister form of corrosion which is relatively rare.

DISCUSSION

Very few changes have occurred over the past year's service, as was expected. The pit-blistering of some sections of the 5052 arch pipe, in fact, seems to have subsided. The corrosion products seem drier and inactive. Two 1.5 x 3-foot areas on the 5052 arch plate were mapped, pits were counted in one area and will be recounted, upon subsequent inspections, to determine further activity. The other area was etch cleaned for evidence of continuing "weeping" in future years.

There is no significant difference between 1973 and 1974 inspections as far as attack of the cladding on Alclad 3004 pipe is concerned. Less exudation of the flocculent reddish-brown compound was also evident during the 1974 inspection.

Action should be taken to prevent further attack of the aluminum pipe at opposite ends of a bare steel culvert liner beneath the CRI&P Railroad tracks south of Canal Street (Location 11). The aluminum appears to be unintentionally grounded or shorted to the steel liner. Cathodic protection is suggested. The steel liner should also be inspected to be sure it has adequate protection. Information on cathodic protection methods is being provided separately.

REFERENCES

1. Memo Report CSR 74-2 Performance of LaSalle, Illinois Aluminum Storm Drain System First Year Inspection by T. J. Summerson, April 24, 1975.

2. LRB 727, pages 95 and 96. Larry Wong - 10/8/74.

ACKNOWLEDGMENTS

Photographs (colored)	D. C. Thomas
Sample removal	Cliff DeGraff
Preparations for inspection and operations of topside equipment	Len Hall

TABLE 1

Sample No.	Location	Pipe Description	Soil Description As Sampled	Soil pH	Min. Soil Resistivity Ω cm	Potential (volts)**	
						Pipe/ Soil	Pipe/ Water
1 (Near 1973 Sample #2)	20 ft. S. of manhole on Canal St. @ 2:00 o'clock	Alclad 3004 72" dia. - 1 x 6	Moist brown sand (11,900 Ω cm as recd. at lab.)	8.2	3200	-0.72	-0.79
2 (Near 1973 Sample #3)	175 ft. N. of manhole 1st & Wright @ 2:o'clock	5052 Arch Pipe 11-0 x 4-11	Moist brown sand (5,200 Ω cm as recd. at lab.)	7.8	1200	-0.78	-0.83
3 (Not sampled in 1973)	40 ft. E. of manhole 3rd & Bucklin	5052 Arch Pipe 11-0 x 4-11	Moist brown sand (98,000 Ω cm as recd. at lab.)	8.4	9600	-0.72	-0.85
4 (Near 1973 Sample #8)	24 ft. E. of manhole on 6th St. between Bucklin & Wright @ 4:o'clock	Alclad 3004 60" dia. - 1 x 6	Mixture of brown sand and ground water (2,200 Ω cm as recd. at lab.)	7.8 (Water* 7.7)	2200 (Water* 4550)	Not Measured	Not Measured
5 (Not sampled in 1973)	3 ft. S. of manhole on 6th between Bucklin & Wright @ 4:o'clock	Alclad 3004 60" dia. - 1 x 6	Mixture of grey sand and ground water (1700 Ω cm as recd. at lab.)	6.9 (Water* 7.7)	1700 (Water* 3700)	Not Measured	Not Measured
6 (Not sampled in 1973)	Manhole S.W. corner 7th & Gooding	Alclad 3004 Corlix Vertical catch basin	Dry brown sand (300,000 Ω cm as recd. at lab.)	8.9	23,500	Not Measured	Not Measured

Sample No.	Location	Pipe Description	Soil Description As Sampled	Soil pH	Min. Soil Resistivity Ω cm	Potential (volts)**	
						Pipe / Soil	Pipe / Water
7 (Not sampled in 1973)	83 ft. N. of manhole 4th & Bucklin	Alclad 3004 66" dia. - 1 x 6	Moist brown sand (27,300 Ω cm as recd. at lab.)	8.5	8200	-0.72	-0.75
8 (Not sampled in 1973)	65 ft. S. of manhole 4th & Bucklin	Alclad 3004 42" dia. - 1 x 6	Moist brown sand (10,600 Ω cm as recd. at lab.)	8.1	2300	Not Measured	Not Measured
9 (1 ft. North of 1973 sample #9)	45 ft. S. of manhole 7th Place & Marquette	Alclad 3004 48" dia.- 1 x 6	Moist brown sand (9,400 Ω cm as recd. at lab.)	8.2	3200	-0.72	-0.80
10 (Area not sampled in 1973)	1 ft. W. of manhole Linburg Rd. & Marquette	Alclad 3004 15" Corlix	Moist brown sand (15,900 Ω cm as recd. at lab.)	8.4	5900	-0.72	-0.80
11 (25-30 ft. south of Sample #1, 1973)	185 ft. S. of manhole on Canal St. (15 ft. S. of steel tunnel liner)	Alclad 3004 72" dia.- 1 x 6	Moist brown sand (29,800 Ω cm as recd. at lab.	8.3	4900	-0.50	-0.75

* Soil/water mixture in samples 4 and 5 separated before testing at CFT, as a result, separate measurements were made of soil and water.

** Cu/$CuSO_4$ reference electrode

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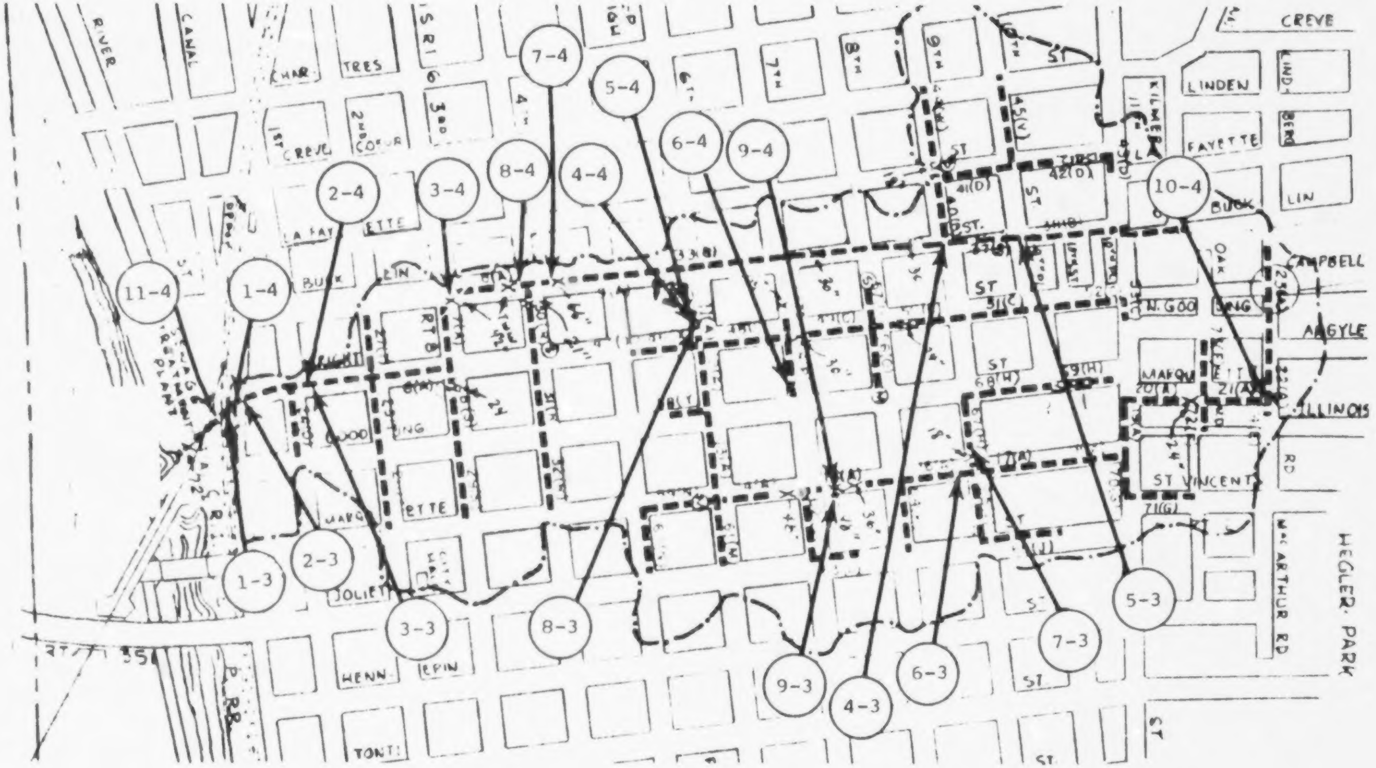
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LA FAYETTE
BUCK
LIN
GOODING
JOLIET
HENNEPIN
TONTI
MARQUETTE
ST VINCENT
MC ARTHUR RD
HEGLER PARK
ILLINOIS
ARGYLE
CAMPBELL
OAK
LINDEN
LINDBERG
FAYETTE
KILMER
SEWAGE TREATMENT PLANT
P. RR.
RT 8
RT 351
24"
30"
36"
66"

Figure 1

ALUMINUM STORM DRAIN SYSTEM - LASALLE, ILLINOIS

Location of one and two year (1973 and 1974) inspection sites and samples.

i.e.--first identification digit - sample number;
second digit year (#3 = 1973 and #4 = 1974 inspection).

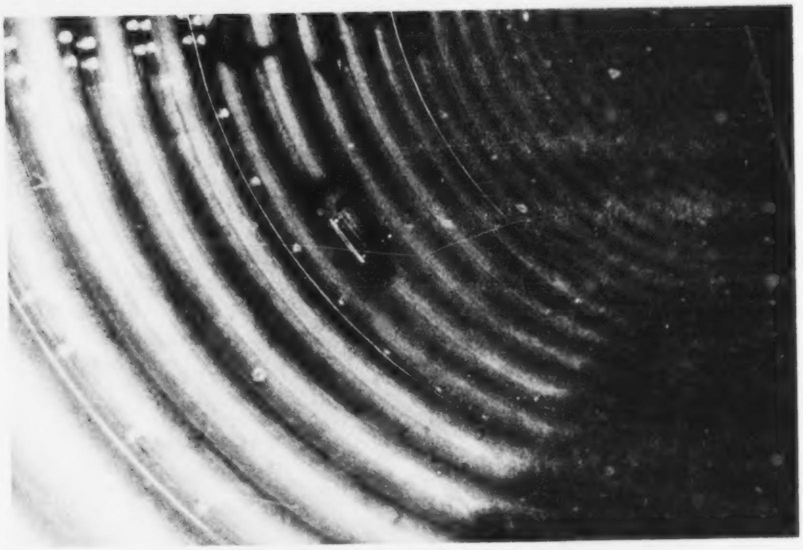


Figure 2

TYPICAL SAMPLE REMOVAL AND REPLACEMENT PROCEDURE LASALLE, ILLINOIS ALUMINUM STORM DRAIN

Two-inch diameter metal sample is removed and covered with a 6-inch rectangular patch attached with stainless steel metal screws. 1974 locations are identified by spray paint.

(Alclad 3004 - 66 inch dia. 1 x 6 at Location 7, 83 ft. North of manhole, 4th and Buckeye.)

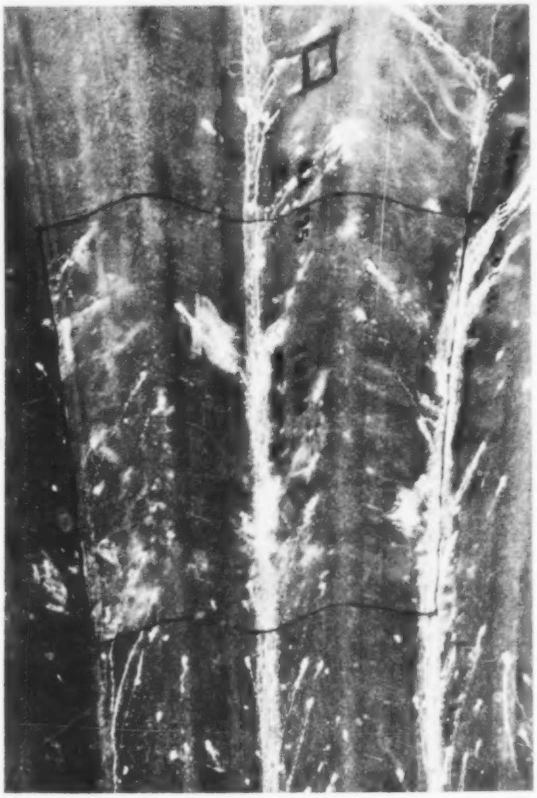


Figure 3

5052 STRUCTURAL PLATE ARCH (0.125-inch)
TWO YEAR INSPECTION (1974)

(First to Third Streets on Wright)

Pit-blistering corrosion and perforations are shown above. Frequency of pitting did not appear to be anymore severe than observed last year in 1973. In order to verify, an area of arch pipe, 1.5 x 3 foot, containing 60 corrosion sites, was identified by marking corners with a center punch and marking each pit site with red ink.

Pit sites will be counted in subsequent inspections. Location - 200 ft. north of manhole on 1st and Wright.

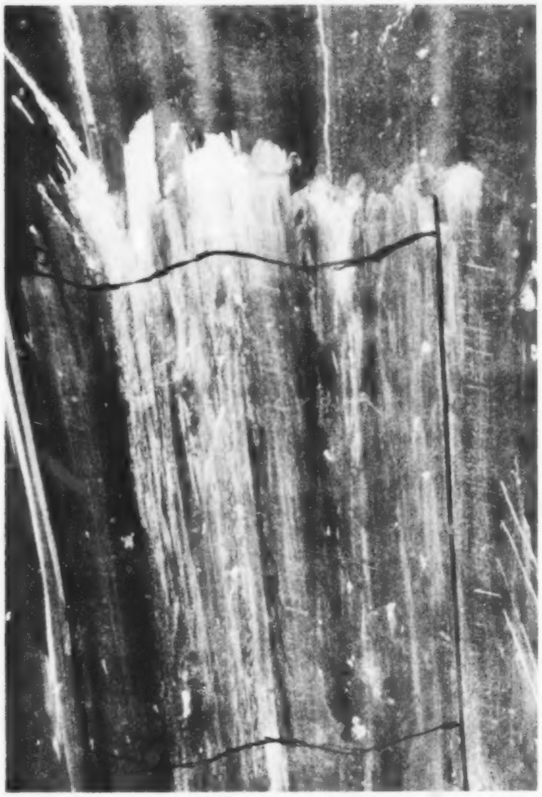


Figure 4

5052 STRUCTURAL PLATE ARCH

200' North of 1st and Wright (1974)

A second 1.5 x 3-foot area of pit-blister corrosion was cleaned with NaOH and water to remove stains and corrosion products. This area will be inspected in 1975 for evidence of further activity.

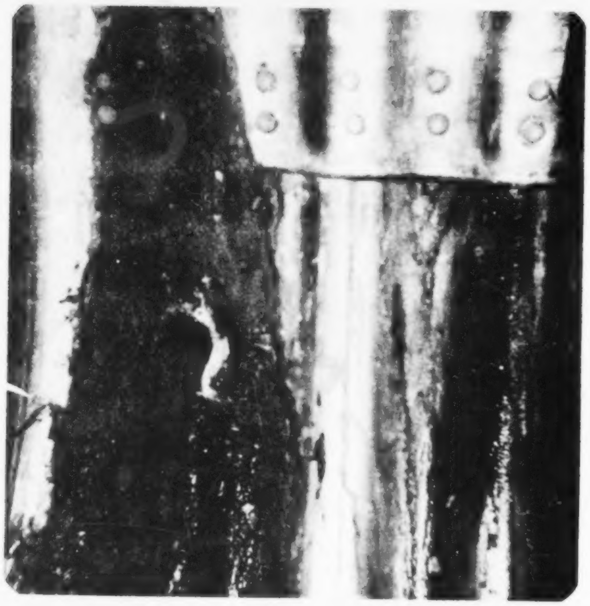


Figure 5

ALCLAD 3004 CULVERT 60" DIA. - 1 x 6
24 ft. East of manhole on 6th St.
between Bucklin and Wright (Location 4)

Black fluid mixture of backfill and ground water flowed out of the hole made when metal sample was taken. (lower left)

Heavy red-brown deposits have been identified as a mixture of hydrated iron oxide (hematite) and calcium carbonate which leach out of the ground water.

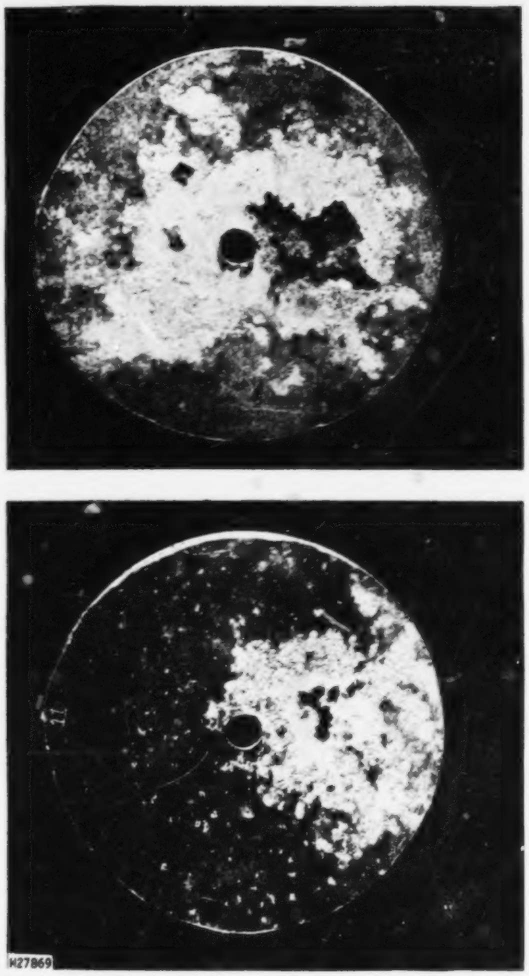
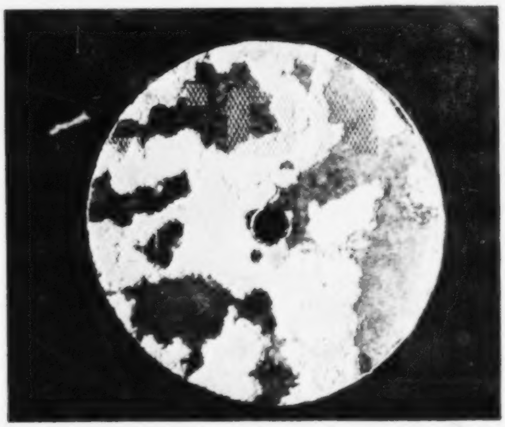


FIGURE 6

PERFORATIONS OF ALCLAD 3004 PIPE CAUSED BY INADVERTENT COUPLE TO STEEL TUNNEL LINER. (location 11)

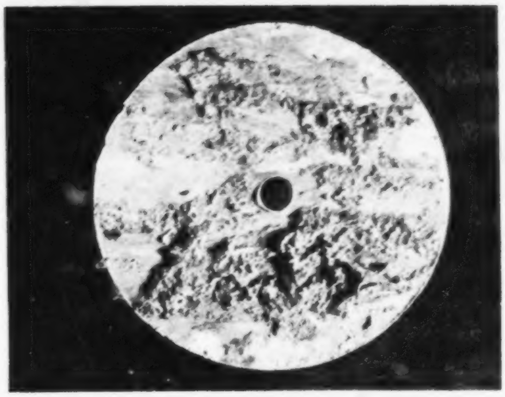
Several perforations were found in the areas of Alclad 3004 adjacent to the ends of a 40-foot-long bare steel tunnel liner. Pipe to soil potential measurement indicates an apparent unintentional ground between aluminum and steel.



SOIL SIDE, Cleaned

High water table, fluid backfill.
Corrosion limited to cladding.

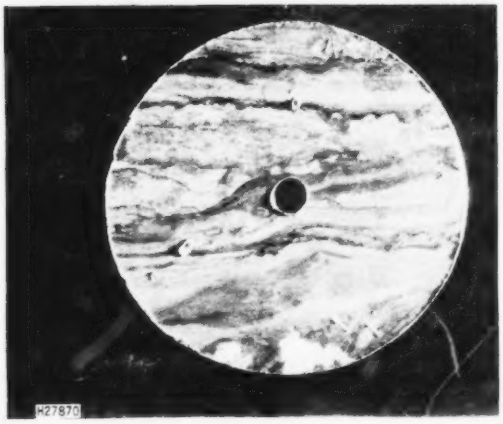
1X



WATER SIDE, as Sampled

Heavy buildup of $CaCO_3$ deposits.

1X



WATER SIDE, cleaned

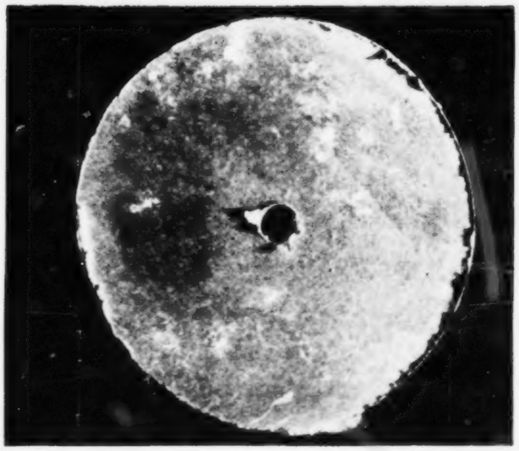
Corrosion (lower part of sample) limited to cladding.

1X

Figure 7

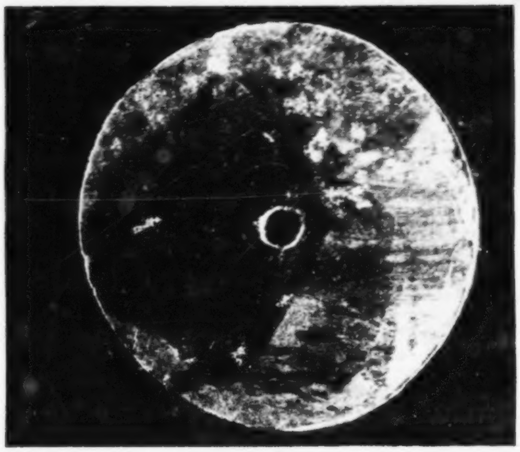
LOCATION-4, EAST OF MANHOLE ON 6TH ST.
BETWEEN BUCKLIN AND WRIGHT

Alclad 3004 60" dia. 1 x 6



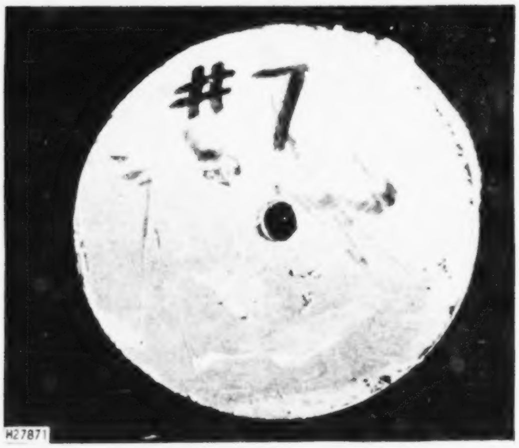
SOIL SIDE, as Sampled

1X



SOIL SIDE, cleaned

1X



WATER SIDE, as Sampled

1X

Figure 8

LOCATION-7 NORTH OF MANHOLE, 4TH AND BUCKLIN

Alclad 3004 66" dia. 1 x 6

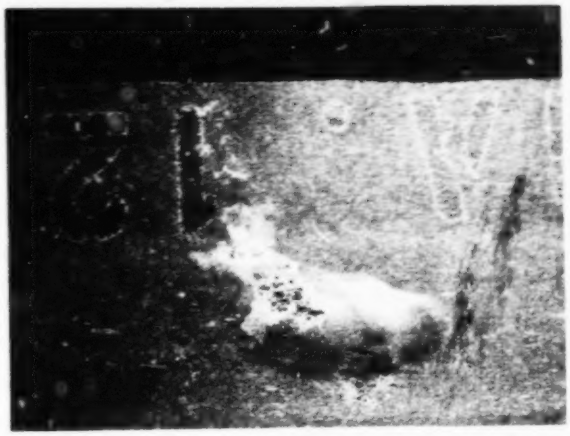
Sample	Size	Location
1	72" dia. 1 x 6	20 ft. S. of manhole on Canal St.
4	60" dia. 1 x 6	24 ft. E. of manhole on 6th St. between Bucklin and Wright.
5	60" dia. 1 x 6	3 ft. S. of manhole on 6th St. between Bucklin and Wright.
6	Corlix Catch Basin	Manhole, S.W. corner 7th and Gooding.
7	66" dia. 1 x 6	83 ft. N. of manhole, 4th and Bucklin.
8	42" dia. 1 x 6	65 ft. S. of manhole, 4th and Bucklin.
9	48" dia. 1 x 6	45 ft. S. of manhole, 7th Place and Marquette.
10	15" dia. Corlix	1 ft. W. of manhole, Linburg Road and Marquette.
11	72" dia. 1 x 6	185 ft. S. of manhole on Canal St., 15' S. of steel tunnel liner.

5X, HF-H_2SO_4 Etch 45 sec.

Figure 9
LASALLE, ILLINOIS ALCLAD 3004 STORM DRAIN
TWO YEAR SAMPLING, 1974

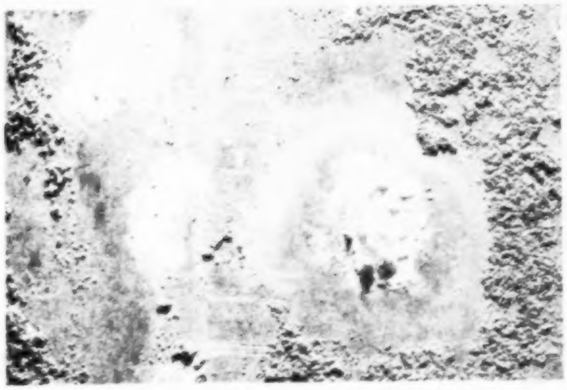
(Soil side up and water side down in these photos)

The corrosion is confined to the cladding layer on all samples except #11 which is perforated due to galvanic action between the aluminum and the steel tunnel liner.



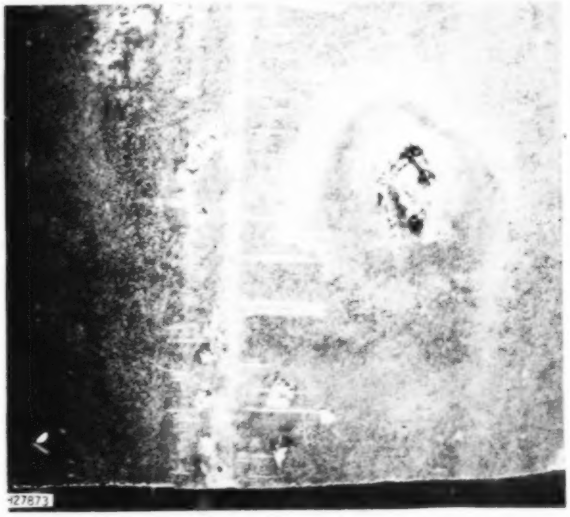
INSIDE - Cleaned

The metal surface is deformed upwards due to the pressure of internal corrosion products



SOIL SIDE, as Sampled

White corrosion products in a mound over the pit and fine granular sand are observed out from the affected area.



SOIL SIDE, Cleaned

The lamellar nature of the pit-blister can be easily seen.

Figure 10
LASALLE, ILLINOIS STORM DRAIN ARCH 5052 PIPE - SAMPLE 2

Pit-blister perforations found in 1973 after one year do not appear to have increased in size or frequency.

5X (unetched)

Figure 11

LASALLE, ILLINOIS 5052 ARCH PIPE (11-0 x 4-11)
TWO YEAR SAMPLING 1974

Soilside, up.

Upper - Location 2 - 175' N. of manhole, 1st St. and Wright. Cross section of pit-blister.

Lower - Location 3 - 40' E. of manhole, 3rd and Bucklin. General pitting type corrosion .020" depth.

APPENDIX D

PERFORMANCE OF LA SALLE, ILLINOIS, ALUMINUM STORM DRAIN SYSTEM

THIRD ANNUAL INSPECTION, 1975

November 7, 1975

ZCFT-75-61-RJH

by

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Applications Research

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CENTER FOR TECHNOLOGY
Pleasanton, California

PERFORMANCE OF LA SALLE, ILLINOIS,
ALUMINUM STORM DRAIN SYSTEM
THIRD ANNUAL INSPECTION, 1975

by

R. J. Hogan

BACKGROUND

In 1971 an aluminum storm drain system was installed by the City of La Salle, Illinois, with Federal Aid (EPA). Alclad 3004 culvert and 5052 alloy structural plate were used.

Three annual inspections have been conducted by representatives of the City of La Salle, Illinois State Highway Department, Kaiser Aluminum, and Chamlin & Associates (consultants for the City of La Salle). These inspections and the remaining annual inspections are being carried out to inspect the aluminum storm drain system for durability and performance during the first ten years' service.

The first and second annual inspections--1973 and 1974--revealed the aluminum pipe was in structurally sound condition (Ref. 1 and 2). Last year, 1974, performance was described as:

a) Corrosion of the aluminum storm drains was superficial with no loss in structural integrity.

b) Corrosion was confined to the thin cladding layer on all Alclad aluminum samples, with the exception of an area of pipe adjacent to an uncoated steel tunnel liner and believed coupled to the liner.

c) Very few, if any, new pinhole perforations had occurred in the 5052 alloy arched pipe during the past year, in fact, corrosion product from existing perforations was dry--indicative of inactivity.

d) Exudation of orange-reddish brown discolorations (amorphous iron oxides) found earlier on the aluminum pipe and concrete catch basins had subsided and most of the iron oxides had been washed away. Only in one area were the discolorations still present.

e) No further buckling of a sharply inclined 72-inch diameter pipe below 1st and Wright Streets.

SUMMARY

The aluminum storm drain system remains in excellent condition after four years' service with no evidence of structural damage.

Six of the eight Alclad 3004 pipe samples showed superficial corrosion, if any, is limited to the thin cladding layer. Sampling at two other locations showed some slight attack of the core, although most corrosion was confined to the cladding.

In the area of the bare steel tunnel liner, several new corrosion sites were noted in the aluminum pipe. Cathodic protection will be installed to protect the steel liner, thereby preventing galvanic corrosion of the adjacent aluminum storm drain.

No new pinhole perforations have occurred in the 5052 structural plate (as proven by actual count in a given area) during the past year's service. In fact, corrosion remains active at only very few of the existing perforations.

There has been no further mechanical deformation (accordioning) of the steeply inclined 72-inch Alclad 3004 pipe, located below 1st and Wright Streets.

STATUS

Annual inspections and laboratory analysis of samples removed will continue.

FIELD INSPECTION

The third annual inspection party, made on August 28, 1975, consisted of:

Chamlin & Associates:	Jim Giordano Al Witzeman
Illinois State Highway Department:	Cliff Adams
City of La Salle, Ill.:	Bill Mallie
Kaiser Aluminum & Chemical Corporation:	Cliff DeGraff Len Hall Bob Vaterlaus Joe Warrenfells Dick Hogan

The storm drain inspection was started at the outfall end of the 72-inch diameter Alclad 3004 - 1 x 6 pipe below the railroad tracks. Locations of the metal samples removed in 1975 (as well as those removed in 1973 and 1974) are shown on the map of the entire storm drain system, Figure 1.

Eleven aluminum samples, one water and eleven soil samples were removed during the inspection. The metal samples were taken with a 2-1/2" hole saw. An aluminum cover patch, with a mastic sealer, was placed over the hole and attached with stainless steel metal screws. See Figure 2. Blue spray paint was sprayed on the 1975 patches for yearly identification. The sample number and date was also spray painted in blue. (The color identification of 1973 sampling was in orange and the 1974 sampling in red.)

Pipe-to-soil and pipe-to-water potentials were measured, using a $Cu/CuSO_4$ reference electrode. (Miller Potential Meter RE-5.) The soils were extracted from behind the pipe and placed in quart-sized plastic containers. Water samples were taken from the outfall end of the system. Inspection notes of the eleven sites follow:

Location 1: Alclad 3004, 72-inch diam. - 1 x 6, 2-1/2 feet inside, from the south end, of the steel tunnel liner. Liner goes underneath the CRI & P Railroad tracks.

The soil side (steel liner side) of the aluminum pipe was coated with a bituminous coating at the time of installation. Behind the metal sample (invert) we found wet sand and approximately 3" of asphalt paving separating the aluminum from the steel liner. No pitting corrosion was evident on the soil side of the aluminum sample taken. Only a small amount of gravel was obtainable.

The cover patch of Sample #1, taken in 1973, was loosened to inspect the steel tunnel liner. Figure 3 displays the rusted appearance of the bare steel liner behind the aluminum pipe.

A pipe-to-soil potential survey was conducted on the Alclad 3004, 72-inch diam. pipe, beginning 25 feet from the south end of the bare steel tunnel liner. Potentials were recorded as follows:

Location	Potential* (Volts)
A - 25 ft. S.	-0.59
B - 50 ft. S.	-0.50
C - 75 ft. S.	-0.70
D - 100 ft. S.	-0.71

---

*$Cu/CuSO_4$ - reference electrode

Location 2: Alclad 3004, 72-inch diam. - 1 x 6, 50 feet south of the steel tunnel liner.

A pipe-to-soil potential measurement at this position confirmed the low (0.50 volt) potential found last year during the 1974 inspection. Metal and soil samples were taken.

Location 3: Alclad 3004, 72-inch diam. - 1 x 6, 17 feet north of the Canal St. catch-basin.

A random side-wall cut was made to observe the soil side of the pipe. The pipe appears to be in excellent condition. A metal sample and soil sample were taken.

The steeply inclined 72-inch diameter - 1 x 6 pipe, on Wright, between Canal and 1st Streets, was examined. There has been no further deformation (accordioning) in the past three years (Figure 4).

Location 4: Alloy 5052 structural plate (arch pipe), 165 feet north of the 1st and Wright Street catch-basin.

A metal sample, containing a pit-perforation was removed for examination. A soil sample was also taken. The white streaking of corrosion products, first noted during the first annual inspection, is shown in Figure 5. All streaking has ceased. Only a few pits remain slightly active. A metal sample and a sample of the brown granular soil backfill were removed.

200 feet north of the 1st and Wright Street catch-basin. A 1.5 x 3 foot area containing 60 pit perforations, counted in the 1974 inspection, was re-examined. Figure 6 shows no new pits have developed. The 60 original pinhole

pits remain. Furthermore, only three of the 60 pits remained active, as evidenced by slight exudation of corrosion products.

An adjacent 1.5 x 3 foot area, cleaned with NaOH and water in 1974, was also examined. Only nine pinhole pit sites in this area remain slightly active one year later.

Location 5: Alloy 5052 arch pipe, 80 feet south of the 3rd and Wright Street cath-basin.

A small pit is visible on the soil side of sample.

Location 6: Alloy 5052 arch pipe, 45 feet E. of the 3rd and Bucklin Street catch basin.

A few pit-perforations were present at this location. Some pitting is present on the sample removed for laboratory evaluation.

Location 7: Alclad 3004 twin 42-inch diameter - 1 x 6, 7-1/2 feet from the inside elbow of the west side twin culvert, 3rd and Bucklin Streets.
No corrosion is present on sample.

Location 8: Alclad 3004, 60-inch diameter - 1 x 6, 24 feet E. of the 6th and Bucklin Street catch basin.

Deposits of hydrated iron oxide (hematite) are still present on both the concrete catch basin and the metal pipe in this area. See Figure 7. A heavy calcium-rich scale deposit is also present on the water side of the pipe. This deposit acts as a protective coating.

Location 9: Alclad 3004, 60-inch diameter - 1 x 6, 40 feet S. of 6th and Bucklin Streets.

Scattered corrosion of the thin cladding layer is noted.

Location 10: Alclad 3004, 60-inch diam. - 1 x 6, 86 feet S. of 6th and Bucklin Streets.

Corrosion of the thin cladding layer is noted.

Location 11: Twin 42-inch diam. Alclad 3004 culverts (west culvert) 65 feet S. of 4th and Bucklin.

Etching of the thin cladding layer was noted. A metal sample was removed from the crown area. The backfill is native soil (reddish in color).

Two pipes near 7th Place and Marquette were inspected. No samples were removed from these areas: (1) 50 feet south, Alclad 3004, 48-inch diameter - 1 x 6 (location of Sample No. 9 of the 1973 inspection). The pipe appears to be in excellent condition. (2) 30 feet N., Alclad 3004 Corlix. This pipe also appears to be in excellent condition.

LABORATORY EVALUATIONS

Eleven soil and metal samples plus one water sample were evaluated at Kaiser Aluminum's Center for Technology (Ref. 3). (Chamlin & Associates has had one water sample tested locally.)

A. Soils

Resistivity and pH of the soil samples (Table I) were measured in accordance with the State of California, Department of Highways Method 643B. Soil resistivity and pH data were comparable with the 1973 and 1974 results.

All soils previously taken have been a brown sandy selective backfill. The soil removed from Location #11 was a reddish-brown clay-like soil, reported to be the native soil. A complete analysis was performed on this sample as well as the fluid fill taken from Location 8. Results are as follows:

Element	Quantity (ppm) #11 (Native Soil)	 #8 (Sandy Fluid Fill)
Chloride	500	136
Sulfate (SO_4)	150	1,175
Nitrate (NO_3)	100	1.8
Phosphate	15	0.5
Suspended solids	1.0	10.7
Ca	280*	400*
Mg	44*	92*
Na	175*	92*
pH	8.3	7.6
Conductivity	1,000μmho(1,000Ωcm)	435μmho(2,300Ωcm)

---

* determined by the atomic absorption method

In addition, a semi-quantitative spectrographic analysis of elements in the native soil was conducted (Location #11). The results are as follows: (in % by weight)

Al	Si	Fe	Cu	Mn	Mg	Ti	V	Pb	Na	Ca	K
3.5	15.	3.8	0.01	0.10	2.0	0.23	0.01	0.001	0.42	5.0	1.0

B. Water

Analysis of the one water sample sent to CFT is on page 9. (The sample was removed at the outfall end of the system.) A water analysis made by ArRo Laboratories in the Illinois area, at Chamlin and Associates' request, is in the Appendix.

CFT Analysis of Water in Drain System - La Salle

Element		Quantity (ppm)
Chloride	-	220
Sulfate(SO_4)	-	550
Nitrate(NO_3)	-	16.3
Phosphate	-	1.7
Ca	-	360
Mg	-	75
Na	-	107
Fe	-	<0.05
Pb	-	<0.1
Cu	-	<0.06
Ni	-	<0.1
Total solids	-	1,426
Total dissolved Solids	-	1,397
Suspended solids		0.3
pH	-	7.5

Conductivity 1,786μmho (560Ωcm resistivity)

C. Metal Samples

The eleven aluminum samples (eight Alclad 3004 and three 5052 alloy) were photographed on both the soil and water sides before and after cleaning. The soil was washed off with water and the corrosion products were removed by ASTM Method 67-1 (hot chromic-phosphoric acid cleaner). The soil side surface of the 2-1/2" diam. coupons (Figure 8) shows varying degrees of corrosion, generally confined to the thin cladding layer. A composite photo of 1973, 1974 and 1975 companion samples removed from adjacent areas on an Alclad 3004 pipe on 6th Street between Bucklin and Wright, Figure 9, indicates most of the corrosion occurred during the first two years' service. The relative amount of uncorroded cladding surface has not changed noticeably in the past two annual inspections.

Representative sections from the eleven metal coupons were mounted in epoxy and polished for metallographic examination. Cross-sections of the eight Alclad 3004 samples are shown in Figure 10 at 5X. Corrosion, if any, is generally confined to the thin protective cladding layer.

Pit-blistering and pinhole perforations found in the 5052 alloy arch pipe during the first inspection (1973) do not appear to have increased in size or frequency over the past two years (as determined by actual pit count in a given area). These small pits (Figure 11) do not affect the structural integrity of the pipe.

DISCUSSION

Very little change has occurred during the past two years' service. The initial pit-blistering corrosion of the 5052 arch pipe has subsided (as determined by actual pit count of a specific area in both 1974 and 1975). Only a few pits remain slightly active.

No differences between 1974 and 1975 inspections were evident as far as the attack of the cladding on Alclad 3004 pipe is concerned.

The installation of anodes to protect the bare steel tunnel liner beneath the CRI&P Railroad is planned for the Fall of 1975. A pipe-to-soil potential survey was taken during the 1975 inspection and will be taken again after the anode installation.

REFERENCES

1. Memo Report CSR 74-2, "Performance of La Salle, Illinois Aluminum Storm Drain System, First Year Inspection", by T. J. Summerson, dated 4/24/74.

2. Memo Report CSR 75-1, "Performance of La Salle, Illinois Aluminum Storm Drain System, Second Year Inspection", R. J. Hogan, dated 5/7/75.

3. Lab Record Book 1059, Pages 30-31, Larry J. Wong, September 12, 1975.

LASALLE, ILLINOIS ALUMINUM STORM DRAIN SYSTEM 1975 INSPECTION

TABLE 1

Sample No.	Location	Pipe Description	Soil Description As Sampled	Soil pH	Min. Soil Resistivity Ω cm	Potential(Volts)* Pipe/ Soil	Pipe/ Water
1 (Near 1973 Sample #2)	125 ft. S. of Canal St. (in tunnel liner-invert)	Alclad 3004 72-in diam.- 1 x 6	Gravel & Asphalt (sampled hole filled with water)	7.8	—	-0.77	-
2 (Near 1974 Sample #11)	185 ft. S. of Canal St. (50 ft. S. of steel tunnel liner)	Alclad 3004 72-in. diam.- 1 x 6	Moist brown sand (25,500 Ω cm as received at lab.)	8.2	5,130	-0.50**	Not Measured
3 (Near 1973 Sample #2)	17 ft. N. of Canal St.	Alclad 3004 72-in. diam.- 1 x 6	Moist brown sand (21,000 Ω cm as received at lab.)	8.3	5,500	-0.75	-0.76
4 (Near 1973 Sample #3 and 1974 Sample #2)	165 ft. N. of 1st & Wright St. catch-basin	5052 Arch Pipe 11-0 x 4-11	Moist brown sand (5,500 Ω cm as received at lab.)	7.7	1,450	-0.78	-0.78
5 (Not sampled in 1973 or 1974)	80 ft. S. of 3rd & Wright St. catch-basin	5052 Arch Pipe 11-0 x 4-11	Moist brown sand (10,600 Ω cm as received at lab.)	8.1	2,500	-0.82	Not Measured
6 (Near 1974 Sample #3)	45 ft. E. of 3rd & Bucklin St. catchbasin	5052 Arch Pipe 11-0 x 4-11	Moist brown sand (12,200 Ω cm as received at lab.)	8.0	2,600	-0.83	Not Measured

Table 1 - page 2

Sample No.	Location	Pipe Description	Soil Description As Sampled	Soil pH	Min. Soil Resistivity Ω cm	Potential(Volts)* Pipe/ Soil	Potential(Volts)* Pipe/ Water
7 (Not sampled in 1973 or 1974)	7-1/2 ft. from elbow of the west side twin culvert - 3rd & Bucklin St.	Alclad 3004 42-in. diam.- 1 x 6 (twin)	Moist brown sand (Not measured as received in lab.)	8.3	4,600	-0.83	-0.79
8 (Near 1973 #8 and 1974 #4 Samples)	24 ft. E. of 6th & Bucklin catchbasin	Alclad 3004 60-in.diam.- 1 x 6	Mixture of brown sand and ground water (saturated - 2,300 Ω cm)	7.6	2,300	-0.86	Not Measured
9 (35 ft. from 1974 Sample #5)	40 ft. S. of 6th & Bucklin St. catchbasin	Alclad 3004 60-in. diam.- 1 x 6	Mixture of brown sand and ground water (saturated - 2,200 Ω cm)	7.5	2,200	-0.76	Not Measured
10 (Not sampled in 1973 or 1974)	86 ft. S. of 6th & Bucklin St. catchbasin	Alclad 3004 60-in. diam.- 1 x 6	Mixture of brown sand and ground water (saturated - 2,250 Ω cm)	7.8	2,250	-0.76	Not Measured
11 (Near 1974 Sample #8)	65 ft. S. of 4th & Bucklin St. catchbasin	Alclad 3004 42-in. diam.- 1 x 6 (Twin)	Reddish brown clay (Native soil) (1130 Ω cm as received in lab.)	8.3	1,000	-0.81	Not Measured

* Cu/$CuSO_4$ reference electrode

**The-0.50 volt aluminum pipe/soil potential indicates a couple to the steel tunnel liner.

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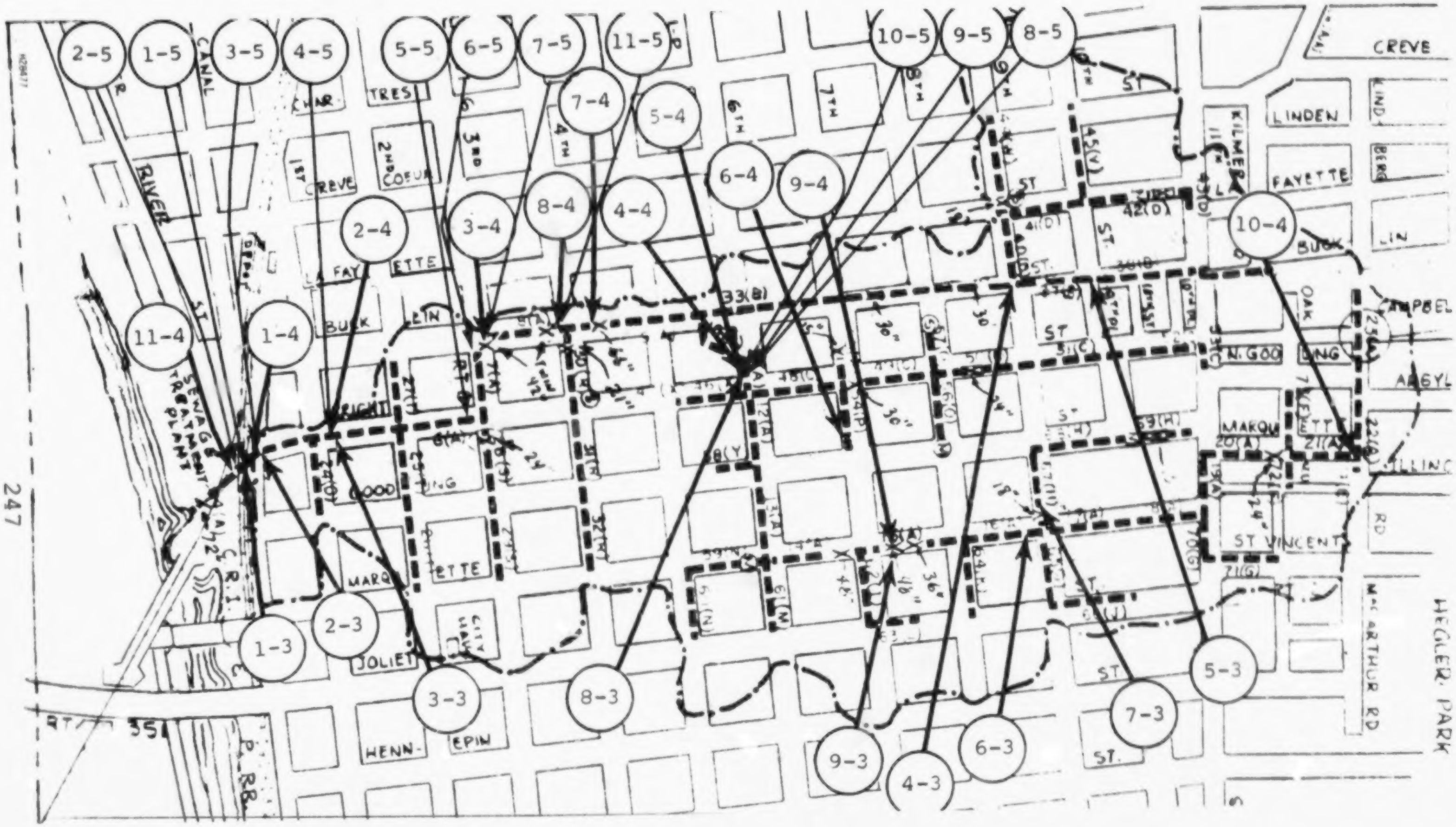

2-5
1-5
3-5
4-5
5-5
6-5
7-5
11-5
10-5
9-5
8-5
7-4
5-4
6-4
9-4
2-4
3-4
8-4
4-4
10-4
11-4
1-4
1-3
2-3
3-3
8-3
9-3
4-3
6-3
7-3
5-3
CREVE
LINDEN
KILMER
FAYETTE
BUCK
LIN
OAK
CAMPBEL
ARGYL
ILLINOIS
ST VINCENT
MARQU
RD
McARTHUR RD
HEGLER PARK
RIVER
CANAL
CHAR
TRES
CREVE
COEUR
1ST
2ND
3RD
4TH
6TH
7TH
8TH
9TH
10TH
ST
LA FAY ETTE
WRIGHT
GOOD
JOLIET
CITY HALL
HENN EPIN
SEWAGE TREATMENT PLANT
C.R.I.
P. R.R.
RT 351
DEPOT
72"
66"
21"
30"
36"
48"
24"
18"

Figure 1. ALUMINUM STORM DRAIN SYSTEM - LASALLE, ILLINOIS

Location of 1st, 2nd and 3rd (1973, 1974 and 1975) inspection sites and samples

i.e. -- First identification digit - individual sample number;
Second digit year (#3=1973, #4=1974 and #5=1975 inspection)

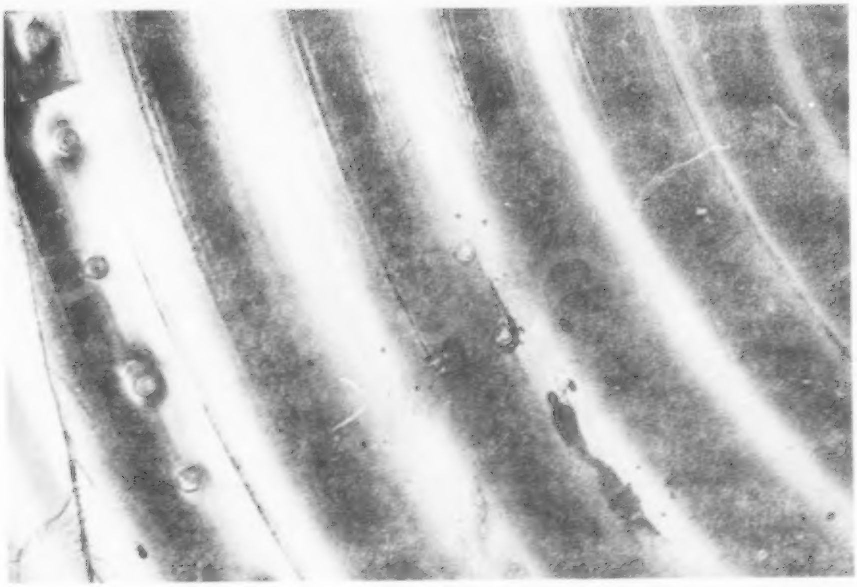


Figure 2. TYPICAL SAMPLE REPLACEMENT PATCH AND BLUE COLOR IDENTIFICATION OF THE 1975 LASALLE, ILLINOIS ALUMINUM STORM DRAIN INSPECTION.

A two and one-half inch diameter metal sample is removed. A mastic gasket is fitted over the hole and a rectangular aluminum patch is set into place with stainless steel screws.

(Sample No. 9, Alclad 3004, 60-inch diameter 1 x 6 pipe located 40 feet S. of 6th & Bucklin.)

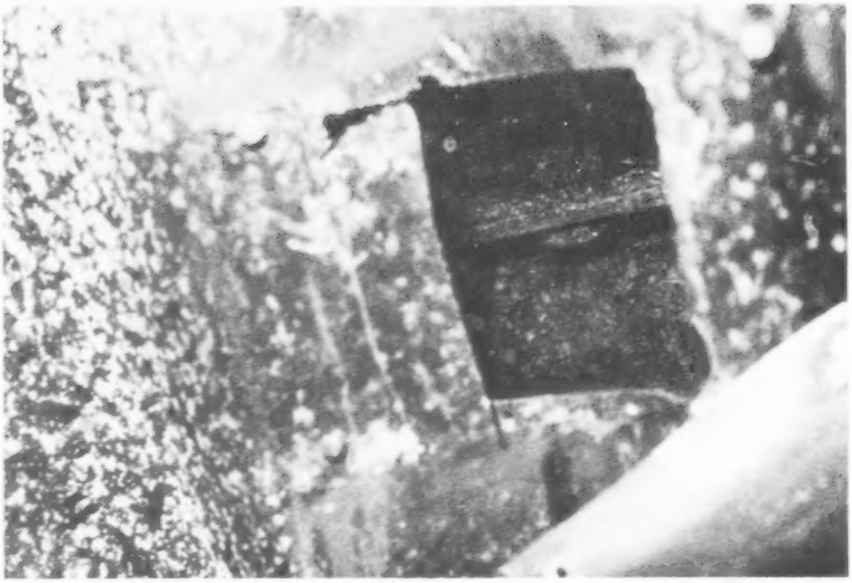


Figure 3. UNPAINTED STEEL TUNNEL LINER EXPOSED TO MOIST AIR BEHIND THE ALUMINUM PIPE.

Inside of the steel liner beneath the CRI & P Railroad displays a rusted appearance from the moist air.

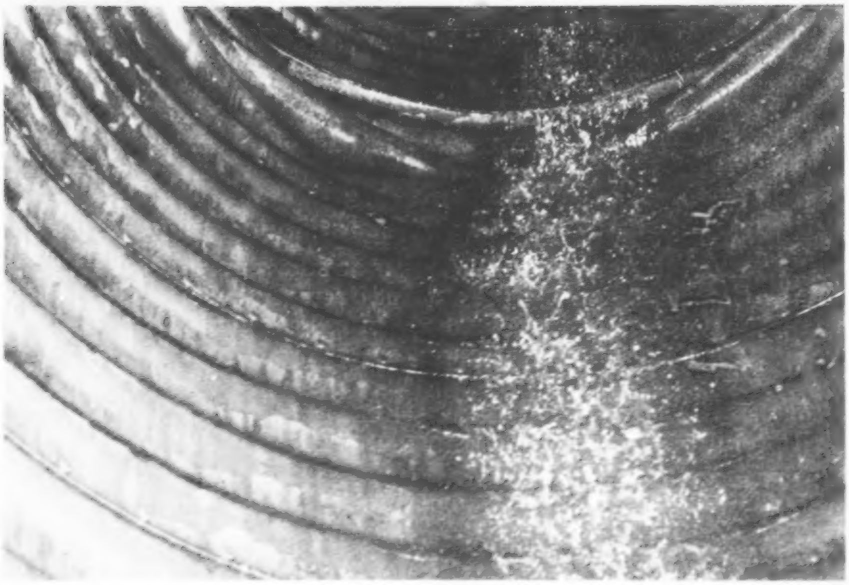


Figure 4. LASALLE, ILLINOIS ALUMINUM STORM DRAIN SYSTEM--1975, 72-INCH DIAMETER ALCLAD 3004 - 1 x 6 - PIPE

There has been no further deformation (accordioning) of the steeply inclined pipe located below 1st & Wright Streets in the past two years.

(The area corresponds with area photographed in Figure 2 of the 1973 LaSalle Inspection Report.)

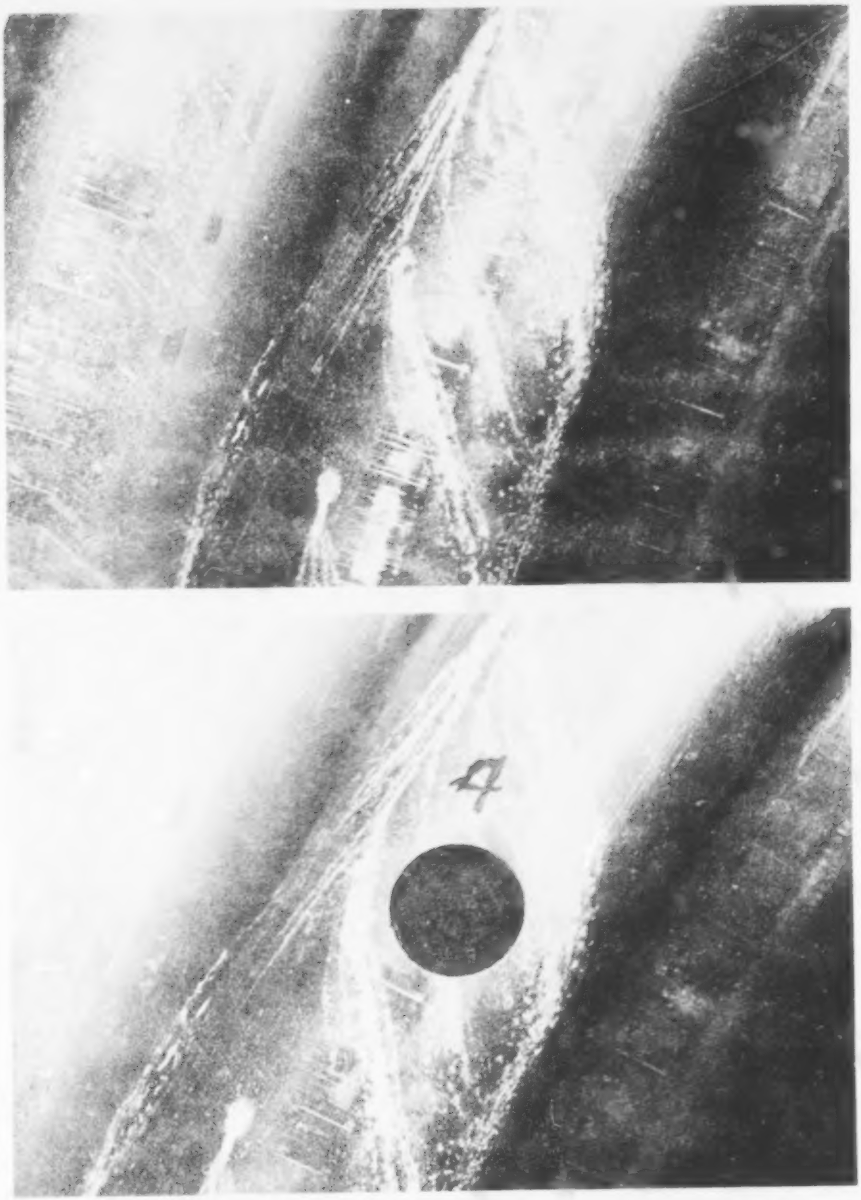


Figure 5. 5052 STRUCTURAL PLATE, 165 FEET NORTH
1st & WRIGHT STREETS. LOCATION 4, 1975

Corrosion products (streaks) from pinhole perforations after the first year service have been dry and inactive for two years. Sample No. 4 with a pinhole perforation was removed, exposing the brown granular selective backfill.

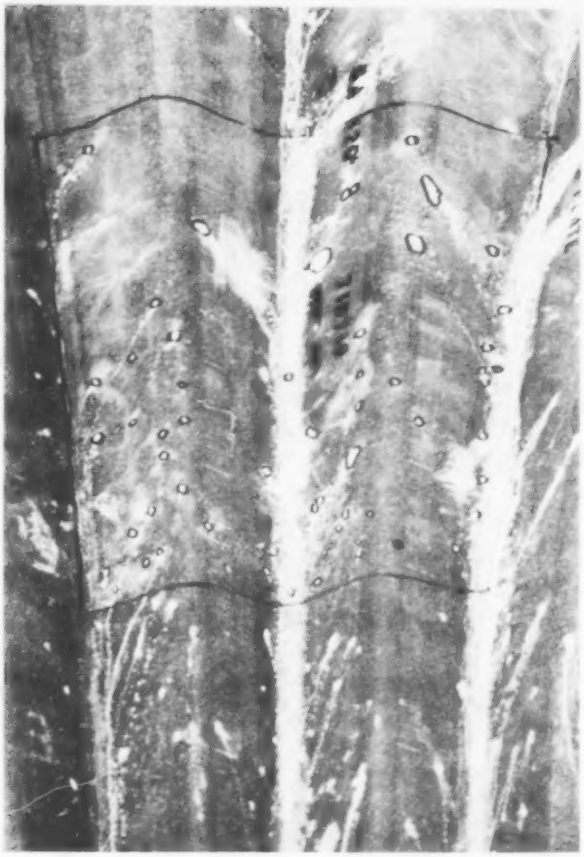


Figure 6. 5052 STRUCTURAL PLATE ARCH (0.125-INCHO

THIRD INSPECTION (1975)
(200 feet N. of 1st & Wright Streets)

A 1.5 x 3 foot area of arch pipe, containing 60 pinhole perforations was identified and photographed during the 1974 inspection. The pit count remains the same in 1975. Furthermore only three of the 60 pits remain active, as evidenced by slight exudation of corrosion products.

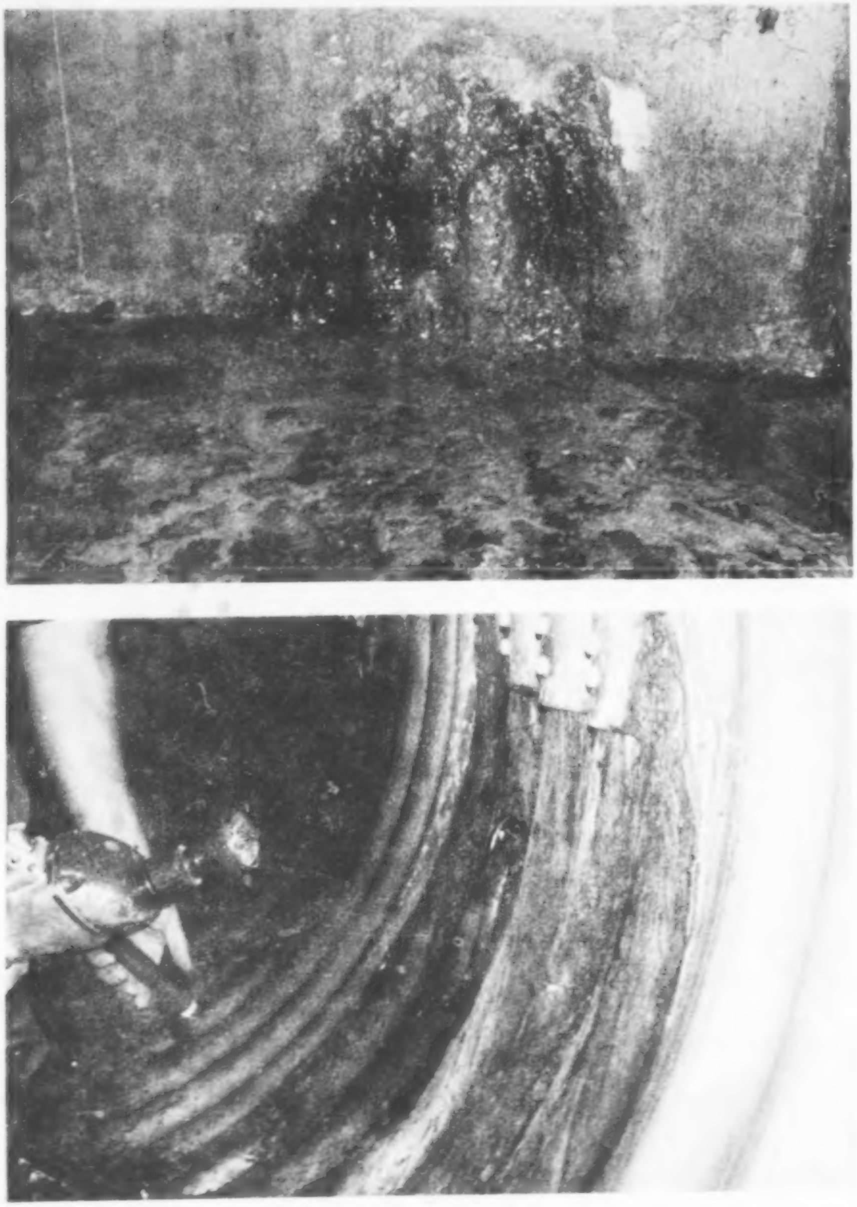


Figure 7. LASALLE, ILLINOIS STORM DRAIN SYSTEM -- 1975 INSPECTION. (6th & Bucklin Streets, Location #8)

Hydrated iron oxide rich solution (hematite as identified by X-Ray Diffraction) is still exuding from the concrete catchbasin and is also present on the aluminum pipe. A flow of fluid backfill (lower photo) is shown as after the metal sample is removed.

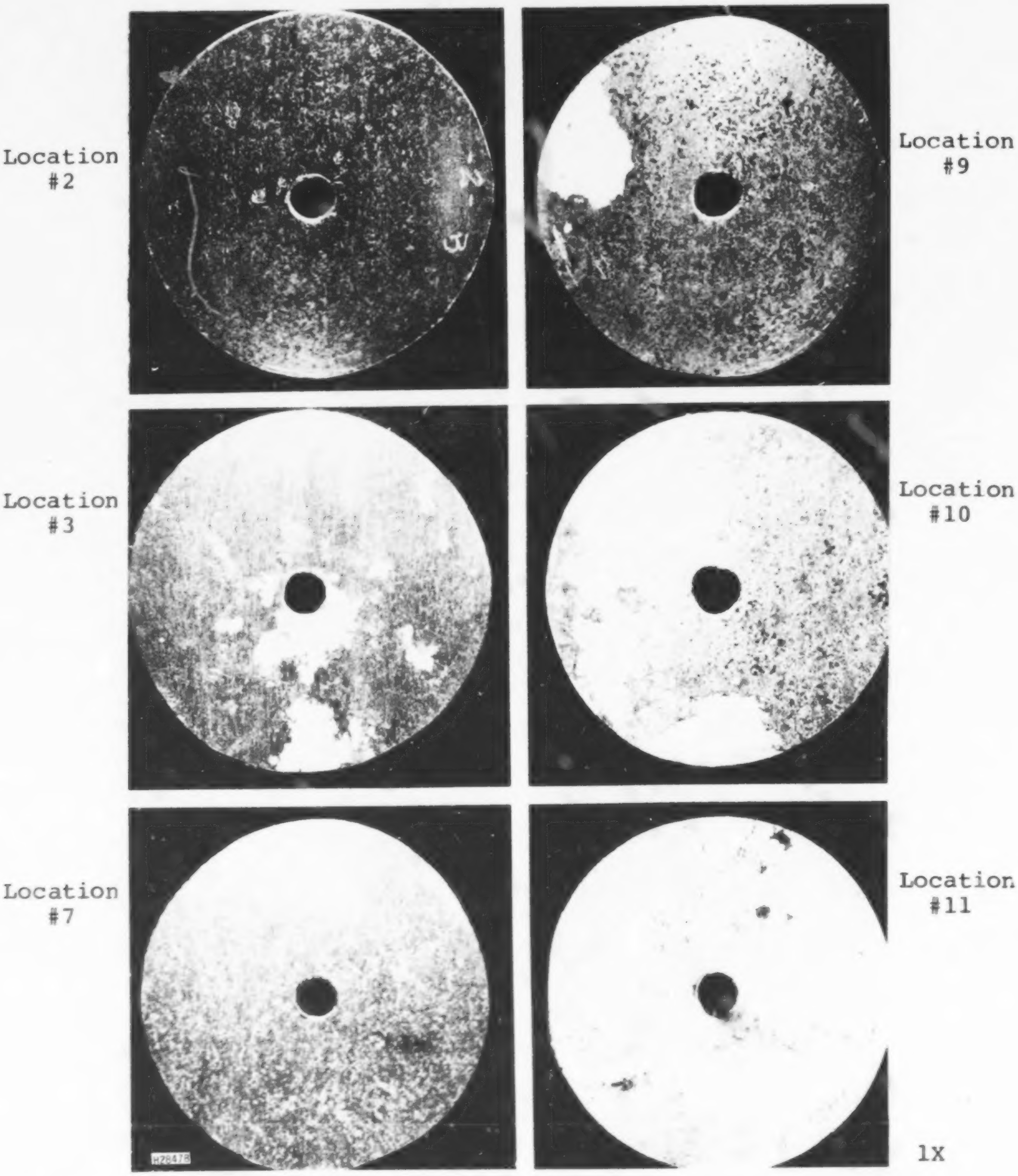
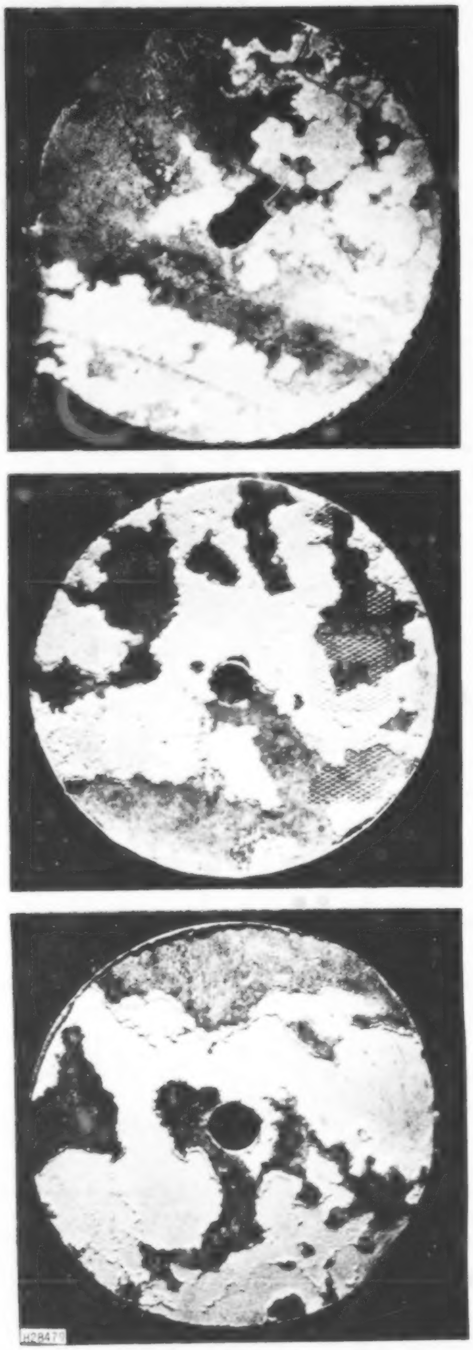

Location #2
Location #9
Location #3
Location #10
Location #7
Location #11
H28478
1X

Figure 8. LASALLE, ILLINOIS ALUMINUM STORM DRAIN - 1975 - 3rd INSPECTION - ALCLAD 3004 ALLOY PIPE - SOIL SIDE (Cleaned). 2-1/2-inch metal coupons, show most surface is unaffected. Corrosion is limited to the thin cladding layer. (Sample #11 shows a light surface etch of the entire cladding layer.)



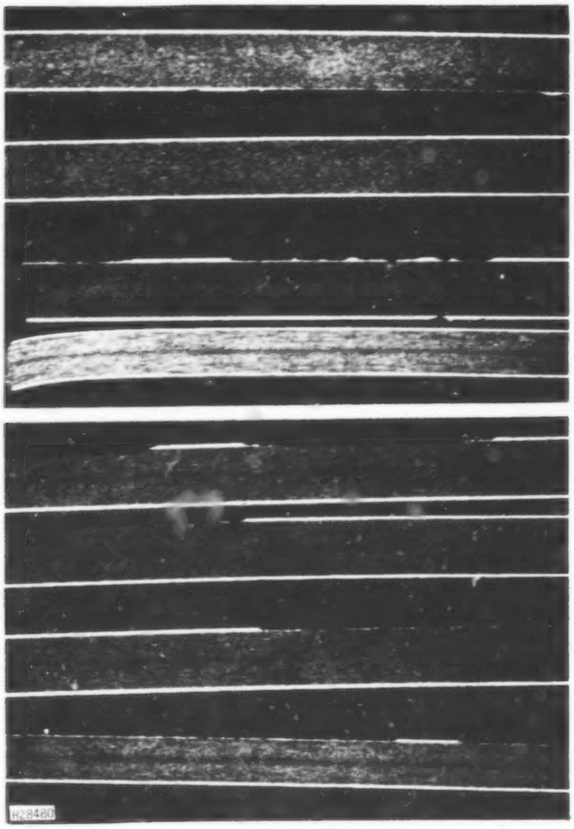
SAMPLED IN 1973
(2 years' service)

SAMPLED IN 1974
(3 years' service)

SAMPLED IN 1975
(4 years' service)

Figure 9. ALCLAD 3004 60-INCH DIAMETER - 1 x 6 PIPE
6th Street between Bucklin and Wright,
LaSalle, Illinois (Cleaned)

Soil side of the pipe showing corrosion of the thin cladding has subsided after the initial attack. All three samples were removed from adjacent areas.



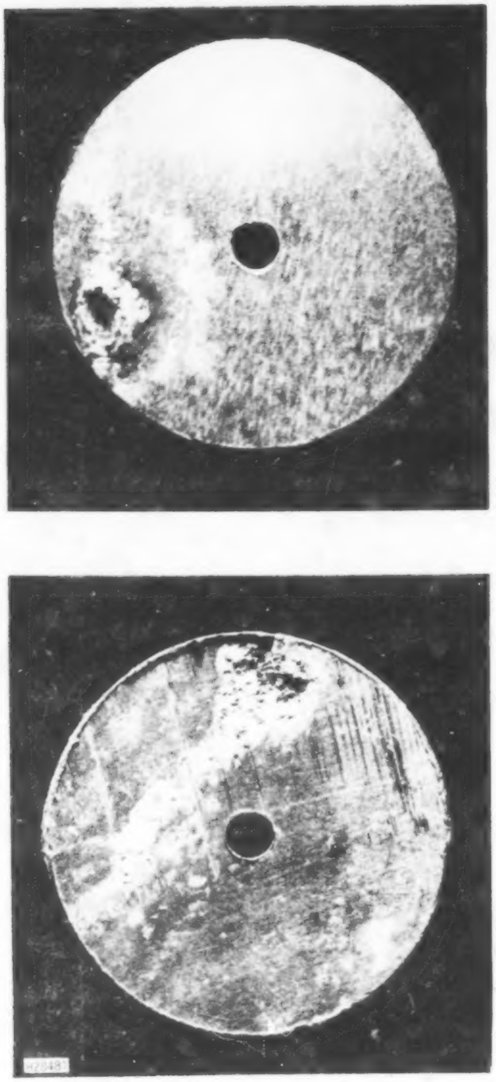
Sample No.	Pipe Size	Location
1.	72" diam. 1 x 6	125 ft. S. of Canal St., in tunnel liner (invert)
2.	72" diam. 1 x 6	185 ft. S. of Canal St.
3.	72" diam. 1 x 6	17 ft. N. of Canal St.
7.	42" diam. 1 x 6	7.5 ft. from elbow of the west side culvert, 3rd & Bucklin St.
8.	60" diam. 1 x 6	24 ft. E. 6th & Bucklin
9.	60" diam. 1 x 6	40 ft. S. 6th & Bucklin
10.	60" diam. 1 x 6	86 ft. S. 6th & Bucklin
11.	42" diam. 1 x 6	65 ft. S. 4th & Bucklin

5X (etched HF/H_2SO_4)

Figure 10. LASALLE, ILLINOIS ALCLAD 3004 STORM DRAIN PIPE - 3rd INSPECTION - 1975

(Soil side up and water side down in these photos.)

The deepest appearing attack on the metal coupons was sectioned and mounted for a metallographic cross section. The corrosion is generally limited to the thin cladding layer.



1X

Figure 11. LASALLE, ILLINOIS STORM DRAIN
5052 ALLOY STRUCTURAL PLATE
Sample 4 - 1975

Soil (upper photo) and water (lower photo) sides of a pit-blister perforation removed from the arch pipe near 1st and Wright Streets (after cleaning.) The size or frequency of pits do not appear to have increased in the past two years.

APPENDIX

ArRo Laboratories Inc. Water Analysis

Three water samples were removed from the outfall of the LaSalle, Illinois storm drain system. One sample was analyzed at CFT and two samples were submitted for analysis to ArRo Laboratories in Joliet, Illinois by Chamlin & Associates.

ARRO
LABORATORIES, INC.

TELEPHONE 815 – 727-5436
P. O. BOX 686 - CATON FARM ROAD
JOLIET ILLINOIS 60434

Date Received 9-17-75
Completed 10-8-75
P.O. Number
Comments

Attention Mr. Mike Rauh
Company CHAMLIN & ASSOCIATE
Address 3017 W. 5th Street
City, State, ZIP Peru, Illinois 61354

ArRo No.	Sample Description	Date	Cartage	Temp °C	pH
2-413E	Samples # 1	9-17	ArRo		
2-414E	Samples # 2	9-17	ArRo		

WASTE WATER ANALYSIS

	2-413	2-414		
ABS Surfactant				
Acids, Volatile				
Acidity (as $CaCO_3$)				
Algicides				
Alkalinity, XXX M.O.	254	262		
Alkalinity (as $CaCO_3$) ph	0.0	0.0		
Aluminum				
Antimony				
Arsenic				
Barium				
Beryllium				
Bicarbonates				
BOD, 5-Day	4			
BOD, Soluble				
BOD, Ultimate				
Bismuth				
Boron				
Bromide				
Cadmium				
Calcium				
CO_2, Free				
Carbon, Total				
Carbon, Total Org. (TOC)				
Chem. Oxygen Dem. (COD)				
Chlorides	174	167		
Chlorinated Hydrocarbons				
a) Gas Chromatography				
b) Sodium Reduction				
Chlorine, Res. (Comb.)				
Chlorine, Res. (Free)				
Chlorine, Total Res.				
Chromium, Hex				
Chromium, Tri				
Chromium, Total				
Cobalt				
Color - Co Pt. Units				
Conduc., Spec.-μmho/cm	1670	1700		
Copper	<0.05	<0.05		
Cyanide, Free				
Cyanide, Total				
Dissolved Oxygen (DO)				
Fluorides				
Hardn., Tot. (as $CaCO_3$)				
Iron, Total	0.09	0.13		
Iron, Total Dissolved				
Lanthanum				
Lead	<0.005	<0.005		
Lithium				
MBAS Surfactant				

	2-413	2-414		
Magnesium				
Manganese				
Mercury - μg/l	<0.2	<0.2		
Nickel	<0.04	<0.04		
Nitrogen, Total as N				
Nitrogen, Ammonia as N				
Nitrogen, Organic as N				
Nitrate as N	3.00	2.70		
Nitrite as N				
Odor - O.I.				
a) Description				
b) Threshold				
Oils & Grease				
Oxygen Demand Index				
pH	7.7	7.8		
Phenols				
Phosphate, Ortho (as PO_4)				
Phosphate, Total (as PO_4)	0.05	0.21		
Phosphorus (as P)				
Platinum				
Potassium				
Selenium				
Silicon				
Silver				
Sodium				
Solids, Total	1555			
Solids, Fixed Total				
Solids, Volatile Total				
Solids, Dissolved	1554			
Solids, Settleable				
Solids, Total Suspended	1			
Solids, Volatile Susp				
Strontium				
Sulfate (as SO_4)				
Sulfide (as S)				
Sulfite (as SO_3)				
Thorium				
Tin				
Titanium				
Toluene Extract				
Tungsten				
Turbidity - J.T. Units				
Vanadium				
Zinc				
Others: Total Coliform	225 per 100 mls			
Fecal Coliform	< 1 per 100 mls			
Fecal Strep	20 per 100 mls			
TPC	720 per 100 mls			
Minimum resistivity*	600	588		

RESULTS IN mg/l UNLESS OTHERWISE INDICATED

Comments * ohms/cm

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